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SCIENTIFIC MEETINGS

REFERENCE SECTION

IGR TRANSLITERATION OF RUSSIAN[1]

The AGI Translation Center has adopted the essential features of Cyrillic Transliteration recommended by the U. S. Department of the Interior, Board of Geographical Names, Washington, D. C.

Alphabet		transliteration
А	а	a
Б	б	b
В	в	v
Г	г	g
Д	д	d
Е	е	e, ye(1)
Ё	ё	ë, yë
Ж	ж	zh
З	з	z
И	и	i (2)
Й	й	y
К	к	k
Л	л	l
М	м	m
Н	н	n
О	о	o
П	п	p
Р	р	r
С	с	s
Т	т	t
У	у	u
Ф	ф	f
Х	х	kh
Ц	ц	ts
Ч	ч	ch
Ш	ш	sh
Щ	щ	shch
Ъ	ъ	" (3)
Ы	ы	y
Ь	ь	' (3)
Э	э	e
Ю	ю	yu
Я	я	ya

However, the AGI Translation Center recommends the following modifications:

1. Ye initially, after vowels, and after ъ, ь. Customary usage calls for "ie" in many names, e.g., SOVIET KIEV, DNIEPER, etc.; or "ye", e.g., BYELORUSSIA, where "e" follows consonants. "e" with dieresis in Russian should be given as "yo".

2. Omitted if preceding a y, e.g., Arkhangelsky (not iy; not ii).

3. Generally omitted.

NOTE: The well-known place and personnel names that have wide acceptance in international literature will be here adopted. However, German-type transliteration e.g., J for Y will not be used.

[1] Due to the individual training and tastes of the translators and reviewers whose work is published in this issue of IGR., it has been impossible to follow the above recommended system. In the near future, however, an effort will be made to standardize transliteration procedures.

THE "PERIGLACIAL"-MORPHOLOGIC EFFECTS of the PLEISTOCENE CLIMATE OVER THE ENTIRE WORLD

Contribution to the Geomorphology of the Climatic Zones and Past Climates IX[1]

by Julius Budel

translated by H. E. Wright and David Alt[2]

AUTHOR'S SUMMARY

The Morphological Effects of Climates Outside the Glaciated Areas During the Ice Age

The paper deals with the climate of the Würm glacial period which is taken as an example of all former cold periods of the Pleistocene epoch. In these periods, while the regions outside the tropics were particularly cold and at the same time drier than at present, the tropical regions were more humid and only moderately colder than today. As a result, there was a different distribution of the major climatic belts over the earth; the change was most pronounced near the poles and least near the equator, as is shown in Figure 1.

Since these climatic belts of the cold period, with the exception of the equatorial regions proper, differed so markedly from those of today, different morphogenetic processes, producing a different set of landforms, were operating in them. This has long been known as far as the former ice-covered zone and the zone of moraines are concerned. The main purpose of this paper is to discuss the "glacial" landforms in all the other climatic zones. (The term "periglacial" should only be applied to relief features of the immediate margins of the former ice sheets.)

Where powerful processes were at work in the glacial periods, and only weak processes in the Holocene, these "glacial" landforms are still the characteristic features of the relief, but where the glacial processes were weak and the Holocene processes strong, the "glacial" landforms have been transformed into those resulting from present day climatic conditions. The regular grading of this relationship is illustrated in Figure 3.

Finally, the paper discusses the question of whether there was just one Würm glacial period, or whether this period is to be subdivided (WI, WII, WIII). The case for a single uninterrupted Würm glaciation is put forward; contrary opinions are discussed and it is shown that the existing difficulties are only apparent and can easily be solved by a simple change in the nomenclature. The new picture of the climatic development of the later Pleistocene which thus results is shown in Figure 2 and 4.

I. The Main Features of the Pleistocene Climate

The term "Ice Age" comes from ice, from the fact that during the geological periods of the Ice Age (Pleistocene, or Diluvial period) which immediately preceded the geologic present (the Holocene or Alluvial period) the glaciers were larger than today over the entire world. This occurred simultaneously in the northern and southern hemispheres and in and outside the tropics. Very early the conclusion - doubtlessly a correct one - that the climate was colder than it is today over the entire earth was drawn from this fact. The colder climate of the Ice Age was the most important feature; the growth of the glacier was only one effect of this cold climate, although morphologically, an especially striking one. The classical period of Pleistocene research saw its goal in the explanation of the glacio-morphological influences of the ice-age climate, i. e. of the Pleistocene glaciers. For this we are indebted, especially through the work of A. Penck, for a basic understanding of the forms of Pleistocene glacial erosion and of the formation of terrestrial mountains, as well as for the explanations of the origin of landscapes of rock-scouring, moraines, glacial gravels in the plains, for the estimation of the Pleistocene temperature decrease, and finally, for the classification or chronology of the Pleistocene. As is well-known, A. Penck distinguished four glacial phases (or as one would say today, four cold phases) and three intervening warm phases with a climate approximately corresponding to that of the recent. Today we must reckon with at least six or seven different Pleistocene cold phases and a correspondingly greater number of warm phases. It is striking in this connection that in each of the cold periods it was colder than the present to about the same extent. This makes it possible for us to disre-

[1] Translated by permission of the author and publishers from the original paper in German, Die "Periglazial"-morphologischen Wirkungen des Eiszeitklimas auf der ganzen Erde (Beiträge zur Geomorphologie der Klimazonen und Vorzeitklimate IX), Erdkunde, v.7, p.249-266, 1953.

[2] University of Minnesota, 1957.

gard the older cold periods which are still uncertain in our classification, and in the following to limit ourselves to the presentation of the best-known, last cold period, the so-called Würm cold phase, and to interpret its conditions to a certain extent as an example of the older cold phases. The references made are always to the truly cold phase, the so-called High-Würm glaciation.

All morphological effects of the Ice Age, differing from those of the present, although caused by the extension of the glacier zone or by the displacement of other climatic-morphologic zones, originate from the ultimate causal event of Pleistocene climatic variation. Therefore we must consider first its basic nature. It is possible from the present state of knowledge to summarize the following six points for the High-Würm glaciation.

(1) At that time the entire world was colder than today; the temperature change was therefore generally in the same direction. No major part of the world was at that time as warm or warmer than during the Holocene.

(2) However, the degree of the temperature decrease was still quite variable. The greatest was proven in central Europe where there were various permafrost soils with ice wedges, in areas which today have a mean annual temperature of 8^{o} to 9^{o}. Today, yearly temperatures of -4.8^{o} to -8.6^{o} prevail at the boundaries of the Eurasian permafrost, according to Gährs[1]. The Pleistocene permafrost in central Europe therefore must have required annual mean temperatures of at least -5^{o} instead of -2^{o}, as heretofore assumed. This corresponds to a local temperature decrease near the ground of as much as 14^{o}. From the depression of the forest border by 1400 to 1600 m. in central Europe, one can deduce an average temperature decrease of a correspondingly thick layer of atmosphere of 7^{o} to 8^{o}. In the tropics, on the other hand, the Pleistocene temperature decrease in the lowermost 5000 m. of the atmosphere amounted to only about 4^{o} according to Flohn [2]. The corresponding cooling in the polar regions must accordingly have amounted to at least twice that much.

(3) This temperature decrease was in any case the primary event; the enlargement of the glaciers was only a secondary phenomenon resulting from it. Because of their large circumference and the great altitude of many inland ice caps, these ice masses influenced the local climate in their immediate vicinity and probably the form of the planetary wind circulation also. Probably some of the abnormally deep range of temperature drop in the lower layers of the atmosphere in central Europe is to be ascribed to such secondary influences of the glaciers on the climate.

In the classical period of Pleistocene research, devoted to the study of the Pleistocene glaciers, insofar as the influences of the glacial climate upon the morphology of unglaciated regions were taken into account, one considered chiefly such near-glacier regions in the immediate front of the great ice sheets, where the structures of soils occur as a result of effects of former, more severe frost phases. These frost effects were referred principally to the above-mentioned secondary influences of the ice sheet on the Pleistocene climate; one therefore spoke of "periglacial region," of "periglacial climate," and of "periglacial"-morphologic phenomena. Inasmuch as many of the morphologic effects of the Pleistocene climate have been discovered far from the former ice sheets, they must be referred not to this climatic secondary cooling by the ice caps, but to the primary Pleistocene climatic change. It is therefore highly misleading to apply the term "periglacial" to all the morphological traces of the Pleistocene climate, which are distributed over the world. In this paper, as a departure from previous practice, that term will be used only in quotation marks. Preferably, one speaks of the morphologic effects of the Pleistocene climate in the individual climatic zones of that time, which are related to those of today, except that they are quite differently distributed. We shall become acquainted with them directly. The Pleistocene ice-sheet zone was only one of them.

(4) The general change in the Pleistocene climate produced a different plant population in all parts of the world, different conditions of soil formation, different geomorphic processes, and also a different assemblage of forms. The climatic zones near the pole especially increased their area. With their penetration into lower latitudes, they naturally entered another radiation climate, but they still remained so related to present-day climatic zones that one can note the effects of the Pleistocene climatic changes upon the earth's surface, that is, by a displacement of the present climatic-morphologic zones from pole to equator. As climatic-morphologic zones, in this sense, one might separate not only the nival-glacial, the arid, and the humid zones. As I tried to show, we can distinguish within the humid region a whole series of equally valid, climatic-morphologic zones which are the causes of quite different assemblages of forms on the earth's surface. Along the meridian of central Europe there are, from pole to equator, approximately the following zones: glacier zones, frost-rubble zone, tundra zone, zone of non-tropical forest (non-tropical soil zone), zone of Mediterranean forest, zone of Mediterranean steppe and desert steppe, desert zone (arid rubble zone), zone of desert savanna, dry savanna, and humid savanna (Flächenspülzone), and finally the zones of the tropical forest (inner tropi-

cal soil zones). Figure 1 shows the average displacement of these climatic or climatic-morphologic zones in the Würm cold phase.

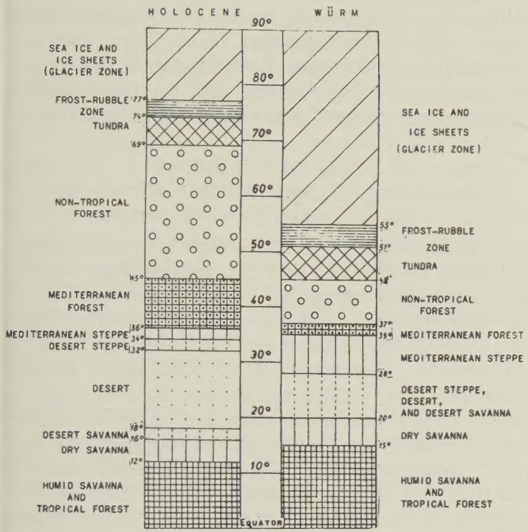


FIGURE 1. The displacement of the climatic zones of the Würm cold phase, showing the average latitude of these zones in the northern hemisphere in the meridional range between 10°W and 35°E.

(5) From Figure 1 it also follows that the displacement of the climatic belts in the higher latitudes was much greater than in the lower, to correspond with the much stronger Pleistocene cooling of the polar regions, compared to the equatorial. The boundary between the glacier zone and the frost-rubble zone here advanced from 77°N to 55°N latitude: about 22 degrees towards the equator, but the boundary of the desert steppe with the desert advanced only from about 32° to about 28°N latitude; only about 4 degrees of latitude. Certainly the humid climatic zones of the inner tropics underwent a slight poleward extension i. e., the tropical desert belt was narrowed from both sides.

(6) The last fact throws a light on the peculiar change in the terrestrial moisture relationships during the Pleistocene. My numerous field observations, and Flohn's theoretical considerations lead to the same results. The two, very strongly-cooled and enlarged Pleistocene polar masses were regions of reduced evaporation and reduced moisture content of the atmosphere, and as a result they were also regions of reduced precipitation. Outside of the tropics the climate was, on the whole, drier than today. But the strong cooling of the polar masses also brought with it a displacement of the two polar fronts into lower latitudes and an intensification of the meridional circulation with much more frequent intrusion of cold air masses into the inner tropics. The Pleistocene cooling caused an increase in precipitation in the tropical regions (in contrast to the regions outside the tropics), i. e., the tropics were at that time generally moister than today. While the thermal climatic change of the cold phase influenced the entire world in the same direction, the alterations in atmospheric circulation caused thereby led to a change of precipitation relations in a different direction: the dry areas outside the tropics were generally more extended at that time; those of the tropics were on the whole less marked, or smaller. There may have existed in individual cases many exceptions to this principle - so far not recognized by us - so it is valid only as a gross average. The changes of such a diverse climatic element as precipitation will never follow such simple rules as the general, primary temperature decrease.

We have thus become acquainted with the salient features of Pleistocene climatic change; we return to their morphological effects. These depend entirely on the Pleistocene displacement of the climatic belts just described. It can be seen from Figure 1 that along the meridian of central Europe from the pole to the sub-tropics (to about 36° to 37°N latitude) all the present-day climatic belts were replaced by completely different ones. That means, that in this entire region, different geomorphic processes prevailed at that time, and an assemblage of forms different from those originating today was produced. These processes, moreover, operated in this region for a much longer time, for the duration of the Würm glaciation alone exceeds by many times the short, less than ten thousand year time-span of the Holocene. Moreover, the majority of the present-day climatic belts were at that time replaced by others of stronger morphologic effectiveness. No wonder, therefore, that in this entire region we still find many form elements which owe their existence not to the present, but rather to the Pleistocene climate.

We also encounter such relic forms still further towards the equator. Here, as Figure 1 shows, the present climatic belts were replaced by others in the Pleistocene; to be sure not completely, but they experienced such significant marginal displacements and internal structural changes - especially the afore-mentioned narrowing of the tropical dry belt - that one can distinctly follow Pleistocene relic forms to the threshold of the inner tropics (about 10° N lat.). Just equatorward from this threshold, i. e. in the inner tropical lowland, it is not in agreement with our present average (naturally disregarding the many vertical displacements of the cold climates in the tropical high mountains as investigated especially by Troll [3]). The slight Pleistocene temperature drop of 4 degrees (i. e. average for the tropical lowland climate,

about +24° today, compared to +20° at that time) has apparently not been able to change perceptibly the character of the vegetation of the rain forest and the humid savanna. Just as the inner tropics are biological preservers of very old floral elements and of the "Tertiary animal paradise," so also in these zones, touched by the cool breath of the Pleistocene, just about the same geomorphic processes have endured, from the younger Tertiary through the entire Pleistocene up to the geologic present (cf. sec. V below).

We must therefore first of all separate the lowland of the inner tropics from a consideration of the morphologic effects of the Pleistocene climate. Also, in the following, the argument should not be based on well-known traces of the Pleistocene glacier zone. We are concerned more with the Pleistocene relic forms which were produced in the intermediate climatic zones, not by ice sheets, but by other geomorphic processes of the Pleistocene cold climate. The area of this zone is distinctly greater and much more important for the morphology of the earth's surface than that of the ancient ice sheet; it includes, as the table shows, more than half of the present (ice-free) continental surface (the former glaciated regions, on the other hand, include only 15%).

Region of Influence of the Climate of the Last Glaciation on the Morphology of the Earth's surface

	Million /km²	%
Present continental surface	149	
Portion of this covered with ice today	15	
Present ice-free continental surface of this:	134	100
1. Essentially formed by the ice of the last glaciation	21	15
2. Influenced by other geomorphic effects of the Pleistocene climate (outer tropics and border tropics not glaciated in the Würm)	70	53
3. Essentially free of Pleistocene relic forms (lowlands of the inner tropics)	43	32

It will again be clear that it is impossible to designate as "periglacial" phenomena, the relic forms of all those climatic zones from the Pleistocene frost-rubble zone to the Pleistocene dry savanna. This concept is applicable more to the portion of the Pleistocene frost-rubble zone closest to the ice, insofar as here the immediate climatic, secondary effects of the ice are distinctly recognizable in its vicinity. The morphogenesis of all other climatic zones was guided by the primary dominating characteristics of the Pleistocene climate. Thus, here we can only speak of the relic forms of the Pleistocene dry savanna, desert steppe, steppe, Mediterranean zone, non-tropical forest zone, tundra, and frost-rubble zone, in which characteristics of the Pleistocene glacier zone are included as a form complex in addition to the others. Parts of these zones today are already as well-known as the Pleistocene glacier zone. The following paper, therefore, considers primarily those Pleistocene climatic belts that have been meaningful for the explanation of our present central European landscape.

II. The Relic Forms of The Oceanic Frost-Rubble Tundra Zone in Western and Central Europe

The distribution of the Würm climatic zones has been reconstructed from morphologic and paleontologic indications by V. Wissmann [4] for eastern Asia, for Europe by the author [5], and finally, by Frenzel and Troll [6] for most of Eurasia. The region of an oceanically influenced frost-rubble and tundra zone is especially clearly differentiated, and includes northwest Germany and West Jutland (north of the polar loess boundary up to the ice edge), also the then dry North Sea and southern England, as well as the higher parts of the Mittelgebirge in France and Germany south of the polar loess boundary. In fact, in the first portion of the Würm cold phase, characterized generally by a more oceanic climate, appropriate climatic-morphologic processes still dominated most of the basin areas of central western Europe, where their traces were then covered in a second, drier portion of the Würm cold phase by the continental loess tundra (see Section III below).

In this frost-rubble-tundra zone especially active and effective processes of weathering, soil formation, and denudation prevailed. They gave the entire indicated area the form and soil profile which, with a few exceptions, remains today. Almost everywhere here, the Holocene geomorphic processes, in contrast to the Pleistocene, were so weak and insignificant, that they could not change fossil landscapes. We live today in the aforementioned area on a fossil tundra landscape; just as within the Würm glaciated area we live on a fossil moraine landscape. What has changed essentially is the forest cover, the weathering type of the uppermost soil particles, the large rivers, steep slopes, the highest mountain regions (where a kind of tundra climate still prevails), and the sea coasts.

Two conditions especially have produced the incomparably greater morphologic effectiveness and expression of this fossil tundra climate in contrast to the present circumstances; the weak and broken plant cover and the soil frost with its different effects. Both conditions are also operative in the present polar climate - almost everywhere influenced by the ocean -, so that we can draw analogies from the present arctic in the reconstruction of this old geomorphic

process, as well as from its preserved traces.

The frequent frost alternation at that time produced a very strong mechanical weathering. Its veneers, one to two, and in exceptional cases three or more meters thick, still cover our landscape on all surfaces with a slope less than 28-32° and are the bases for most of our cultivated land. The fossil tundra character of this soil cover is revealed by its structure. On very gently inclined slopes there are structures of "microsolifluction" (Troll), to which we ascribe all kinds of fossil structure soils: simple polygon soils as well as complex involution soils. Likewise, the ice wedges (loam wedges at present), cutting through the entire soil in great nets, are associated with gentle slopes and with especially cold regions of the tundra climate, for they occur only in the region of permafrost.

On slopes inclined more strongly than 3°, the fossil tundra soils gain the structural traits of "macrosolifluction." The mechanically weathered rock particles are found no more in rhythmic arrangement in a narrow area; their mobility, set in motion by frost in combination with gravity, leads to a slow downslope migration of the entire soil profile. The marks on bedrock known as "Hakenschlagen" are an indication. A second is that the fine and coarse particles are thoroughly mixed in the entire profile because of the gliding movement. In every soil profile originating by weathering, the coarse constituents naturally increase downward. In fossil tundra glide soils (macrosolifluction soils), generally even the coarsest blocks lie in the upper part of the profile, where the resistant constituents, migrating from upslope, according to the prevailing mechanism of movement, must be enriched. Thus, many "block-seas" in the Mittelgebirge rest on foreign bedrock. A third, less common criterion is the traces of micro-movement on the surface of such tundra soils: either stone stripes with the slope inclination or small rubble terraces and block ridges across the slope (the latter as indicators of once thickly grown tundra). A fourth criterion is the presence of many coarse constituents, especially elongated ones, with the long axis in the direction of the slope (according to Richter). Finally, the rounding of coarse fragments in such tundra soils is very slight (even generally less than in moraines), for the frost-breaking continually produces new, sharp edges, and their wearing occurs slowly with the pushing glide motion. Measurements according to the rounding index of Cailleux and Tricart [8] yield almost the smallest values of all types of fragments anywhere. The principal time of movement of these fossil solifluction soils was in the spring, when, with the substratum still frozen, the snowmelt changed the entire weathering layer into a completely water-saturated soup. In the present-day arctic, movements of such thick rubble-covers up to 3 m. have been observed in a thaw period by Dege [9]. We also find such fossil rubble-covers transported several kilometers over foreign rock with very coarse blocks and on slopes of only 2° inclination. Thus, the present lack of movement of this old tundra zone could be shown not only in cultivated land by undisturbed field boundaries, trails, and the like, but also in undisturbed upper bedding of peat and loess covers, and undisturbed penetration of post-glacial weathering horizons by such deposits.

The denudation of the land by these processes are very severe. The moraine landscapes of the Riss glaciation which were not covered by ice in the Würm glaciation, but which were probably subjected to the full force of the contemporary tundra climate, have lost all their characteristic forms: their lakes are filled-up and their once-irregular relief has been changed into a completely uniform, hilly landscape which is exposed to the sea and which can still be designated as a moraine only by its geologic structure. This Pleistocene tundra climate, however, has impressed the same gently undulating forms on all older rocks; we owe to it the beloved, gently-undulating profile, the beauty of our hill-lands and Mittelgebirge. The modern erosional processes, effective because of the artificial destruction of the plant cover, are shown by the formation of sharply-bounded erosion gullies.

At that time, tremendous quantities of rubble migrated to the valleys. They accumulated primarily in the uppermost branches of the drainage network which, in the form of small trough-shaped valleys (Muldentälchen) or dells (dellen) spread over our land area almost like a blanket, in a branching network, whether we are in the old-moraine region of Markland or Schlesien, in the Bavarian Tertiary hill country, on the plains of the southwest German provinces, or on the heights of the Rhine Schiefergebirge, the Harz, or the Erzgebirge. They extend often only 2-3 km or also in many cases 6-8 or even 10 km before they unite with one or more other such dells into a large valley and thereby lose their characteristic form. This is marked especially by its flat basin-like cross-section, without valley floor, and by the lack of a stream or rill which could produce such a floor. There are today, throughout their length, dry valleys, the largest of which, at best, contain a moist ground-water zone in their middle (and many times an agricultural drainage ditch). They show broad bends like other valleys, but, to our astonishment, we do not see the usual change from steep to gentle slope, in fact, the inner slope is often somewhat steeper. All this shows that the usual river effects of our climate never dominated, but that a very different erosion mechanism

created these valleys. In the spring, i. e. the morphologically effective season of that time, they were filled not only with rubble but also with water. At the time of snow melting, the substratum in this climate was still frozen, so it could not be deeply infiltrated.

The evaporation was slight in this cool climate. Furthermore, no thick plant cover checked the flow, thus deeply saturating the rubble of the little trough valleys and making possible a slowly streaming linear movement. These slow rubble streams have themselves created an important part of these little trough valleys by linear erosion. At the same time, to be sure, there is also found true, linear, deep erosion by meltwater streams. But the rubble penetration from the sides was clearly so great that such streams were always suffocated and could not meander freely, thus creating neither a true valley flow nor the opposition of undercut and slip-off slopes.

In consequence, we find in the bottoms of the troughs of such dells, scarcely stratified and very slightly rounded material. In fact, according to Tricart, the strong water saturation of the rubble produced with refreezing an especially active frost breaking, so that here we often can find even somewhat smaller rounding indices than in tundra soils on the slope. In platy, broken rock (as the platy Muschelkalk or Jurassic chalk), flat fragments with sharp edges and thus of angular or chipped outline are characteristic.

Little trough valleys (Muldentälchen) of similar type can also originate in other climates by other processes. For proof of whether we are actually concerned with such dells formed by solifluction erosion in a tundra climate, the existence of such frost-broken rubble is to be cited. In addition, there is a further, very characteristic indicator: the frequently common asymmetry of such dell valleys. The steep slopes in central Europe are thus exposed to the south and west, the gentle slopes to the north and east or southeast. Lösche and Poser [10] assumed as the cause a clear exposure to the sun (quicker drying in the spring and thus less erosion and greater steepening on the south and west slopes). Steep slopes facing northwest, however, cannot be explained in this way, and for these, a different kind of wind exposure must have been essential (probably stronger moistening of the gentle slopes facing northeast to southeast by drifting snow and thus faster erosion there [11]). In addition, however, to explain the origin of valley asymmetry, the effect of running water must be introduced: more intensified rubble supply on one side pushed the intermittent meltwater stream to the other side, where its one-sided lateral erosion brought in to existence the striking steepening of the opposing side. With the preservation of their asymmetry the dells show not only an especially characteristic trait of their cold-climatic mechanism of origin, but clearly once more the contrasting, striking weakness of the Holocene valley-building processes, which are able in no way to erase the characteristic fossil form of the dells.

The gradient of each erosion form, and thus of the dells, decreases rapidly down-valley. With it, the self-movement of a rubble, saturated so strongly with water, diminishes. It practically ceases with a gradient of less than 2^{o}, because then the internal friction becomes too great. In the dells therefore, much rubble remains lying nearby. But the water flow runs on farther, unhindered. Thus there came a time when, as in the tundra climate of the cold phase, the rubble supply could no longer impede the free movement of the water. Usually this point was reached at the junction of two dells with similar gradients. If a one-sided lateral erosion already existed in the asymmetric dell, this became two-sided. The stream undercut both slopes while oscillating changeably, imparted to them a sharp basal nick, and spread between them the rubble contributed passively in great quantities. At the transition point a "Kastental" or soled valley was formed directly from the trough valley. It shows in its bends the normal asymmetry of the undercut and slip-off slopes; uniform asymmetry is rare.

The floor of these valleys is usually gently curved in cross-section; for with the strong flow of rubble from the upper slopes it practically consists of a succession of mud fans arranged beside one another on the valley side, fans which extend their form at the time of snowmelt. Today these valleys are occupied mostly only by small streams which, following the low lines on the edge of the old mud fans, generally flow on the sides of the present valley floors in order to pass over the start of such a mud fan on the other side. The small channels in which they wind through the extra-broad fossil valley floors are the only traces of any Holocene erosion.

Next to these small channels of recent creeks or small streams, these valley floors preserve unchanged the fossil gravel of the tundra-phase mud fans. In contrast to the rubble of the dells, material of the valley floors is transported by running water and is thereby sorted, stratified (often cross-bedded), and already relatively well-rounded. In beaches with coarser fragments, the arcuate position against the stream channel and the regularity of the long axes of the fragments across the stream direction are characteristic, as in all river deposits. Inasmuch as fresh solifluction material was always introduced from the sides, these gravels are often strikingly coarse. But this coarse texture often does not reach to the present surface of

the valley floor. The floor is almost always covered instead with a bed of fine material sharply visible from below: the floodplain sand or, especially in loess-rich regions, the floodplain loam. It has nothing to do with the Pleistocene shaping of the valleys of Mittelgebirge, but, according to Mensching [12], it is an expression of a high-flood deposit at the time of the first (Neolithic-Bronze Age) forest-clearing by man. The river discharge, artificially increased at this time, produced enormous floods whose mud was spread over the entire valley bottom. With very strong flood water this process still goes on today. Occasionally, thin deposits of the river bed itself, occurring at such times within the floodplain, have nevertheless been able to change the basic fossil form of the valley floor, but only by a trace.

With our larger Mittelgebirge rivers, perhaps the Leine and the Weser, according to Mensching [13] there was inserted between the time of the main Würm formation and the Bronze Age covering of floodplain loam on our valley floors, still another valley-forming phase in which a part of the old valley near the river was buried on the average several meters deep, so that one can distinguish an upper and a lower "Niederterrasse." In this case the floodplain loam cover lies mostly on the lower Niederterrasse, while on the upper, the old Pleistocene gravels extend to the present surface. Probably the lower Niederterrasse originated during the cold retreat of the so-called Younger Tundra phase at the end of the Würm Late-Glacial [14].

That the tundra-phase origin of our present dells and Mittelgebirge valley floors, which are thus actually grouped as Niederterrasse (not glacial, i. e. not produced by glacier streams), followed in fact the main Würm phase, could be recognized in southern Germany, in the Inn and Danube regions earlier by their association with true glacial Niederterrassen [14]. In our Mittelgebirge rivers, in fact, the dells as a main glacial feature always emerge on the "upper Niederterrasse". Where this is lacking, the dells and small lateral floor valleys often open into the main valleys with a small scarp. The preservation of this break in gradient is a further proof of the weakness of post-glacial compared to main glacial, and even late-glacial morphogenesis.

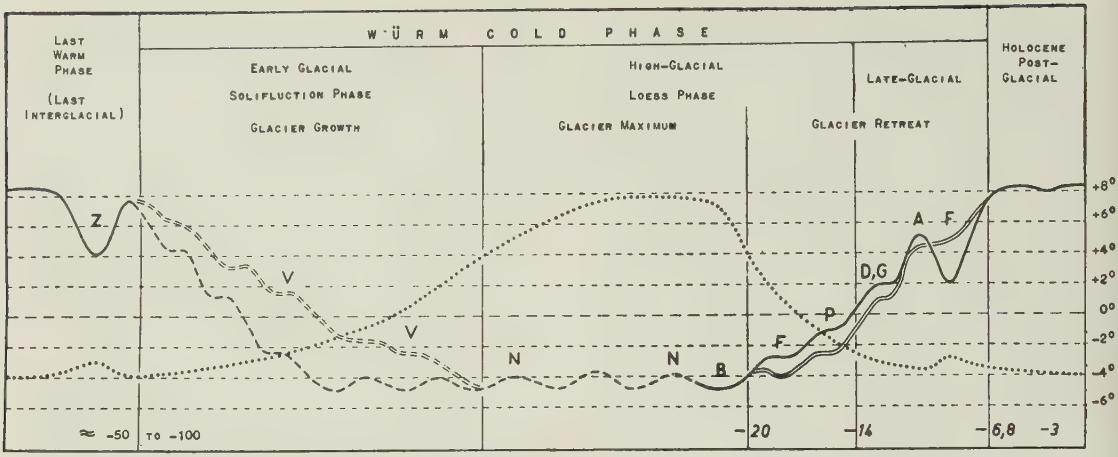
Considering all the cold phases, such a period of stronger sheet and linear erosion under the influence of a tundra climate set in several times over central and western Europe. In linear erosion, the rubble streams and rivers of the later cold phases frequently followed the trails already traced in earlier cold phases. These thus preserve only their last formation in the Würm cold phase. Remains of earlier cold phases are mostly not encountered but probably in all our river valleys, remains of earlier, cold-phase valley floors are preserved in a system of older terraces. Every glacial phase began with a phase of stronger vertical erosion as a sign of increased water flow. With the increasing availability of solifluction rubble the Pleistocene rivers, however, were overloaded again and again with gravel: the broad gravel floors originated by the deposition of the above mentioned linear mud fans accumulating by contemporaneous lateral erosion; they are almost unexpected from the last glaciation, but are preserved from earlier cold phases in the remains of these terraces.

Outside the high mountains, in which today very strong erosional processes still prevail, central and western Europeans live in a fossil, Pleistocene, tundra landscape. In its plant-poor expanses the wind also played a great role. One of its traces are the inland dunes, which we find in the old moraine surfaces of northwestern Germany - in the old Urstromtaler of northeastern Germany, in the Rhine plain, and in Hungary. Their forms were unstable during the high-glacial phase and experienced a new, further development during the cold retreat of the Younger Tundra phase in the Late-Glacial. They were stabilized first thereafter, by the fully developed plant cover of the Post-Glacial. Their present forms thus come from the Late-Glacial. Only on the sea coast, freed of vegetation by storms and surf, does their formation still continue today.

III. Relic Forms of the Continental Loess-Tundra and Loess-Steppe in Central and Southestern Europe

The Würm glacial phase was a single great cold period encompassing in all several thousand years. We know that at the end of the last warm phase, several precursors in the form of short, overlapping, somewhat cooler periods preceded it, (the so-called Zwolle stadial of Dutch authors) and that likewise the ice retreat at the end of the Würm cold phase took place in small fluctuations. It is to be assumed that during the maximum of this cold phase, smaller climatic fluctuations of similar magnitude occurred. According to our present knowledge, however, none of these small fluctuations brought about such a strong warming that one could speak of a true "interstadial" within the main Würm cold phase; i. e. of a mid-phase of strong ice retreat (even to central Sweden) and a prevailing reforestation of the areas around the North Sea and the Baltic Sea. Rather, most of central Europe during the entire main part of the Würm remained uniformly in the range of the frost-rubble and tundra zones of that time [15].

This tundra climate, nevertheless, did not remain completely uniform during the course of the Würm. It can be subdivided into three main phases -- without regard for these small



TEMPERATURE CURVE (PRESUMED); NUMERICAL SCALE ON RIGHT; MEAN ANNUAL TEMPERATURE NEAR ICE IN CENTRAL EUROPE; LOWLANDS.

GLACIATION CURVE (PRESUMED).

HUMIDITY CURVE.

NUMBERS ON THE BASE LINE: THOUSAND YEARS BC, SCALE INCREASING TO THE LEFT.

FIGURE 2. The climatic phases of the Würm cold phase, shown by curves of temperature, glaciation, and humidity. Latter shows humid values below, dry above. One sees the lag of the glaciation curve with respect to the temperature curve, and, nearly opposite, the reciprocal course of the humidity curve with a dry maximum in the High-Glacial loess phase and a smaller maximum during the Finiglacial recurrence of cold temperature.

Z = Zwolle stadial
V = Advance phases (hypothetical)
N = Presumed climatic oscillations during the High-Glacial
B = Brandenburg phase
F = Frankfurt phase
P = Pomeranian phase
D, G = Daniglacial, Gotiglacial
A = Alleröd interstadial
F = Finiglacial (Younger Tundra phase)

fluctuations (cf. Figure 2).

(1) The cold-oceanic solifluction phase: the Early Glacial. This is the period in which the remolding of the land surface of western and central Europe, as described above, was completed with the onset of the cold climate, the tundra vegetation, and the ground frost. The ice sheet was growing at this time -- on its part encompassing certainly several thousand years alone -- to its maximum.

(2) There follows the more cold-continental period of the High-Glacial proper in which occurred the deposition of glacial loess. We therefore term this the loess phase. The ice sheet now reaches its full size. The secondary climatic effects of this condition must alone lend a greater continentality in the vicinity of central Europe. With the general eustatic low stand of the ocean caused by glacier growth, the coasts of Europe retreated far to the west: the Baltic Sea was ice-filled, and the southern half of the North Sea and the Arnel Sea were mainland. Likewise the dynamic and thermal influences of the ice caps must also promote in their vicinity the formation of dry, high-pressure situations. There is thus the question, whether in this period still further general changes in glacial climate did not occur in the same direction. In each case an essentially drier tundra climate now set in from the southeast, which in the lower basin elevations of this region led to persisting sedimentation of fine, eolian loess dust. Thus in these regions the humid solifluction-tundra was replaced by the "dry loess-tundra". This graded toward the southeast into a loess-steppe. Into this with increasing continentality, the loess was deposited in much thicker cover. The highest summer temperatures made possible tree growth here, but because of the prevailing dryness there were only local formation of woods. Thus the loess tundra and loess steppe offered similar morphogenetic meanings. The boundary of both regions in the Würm ran from about the Alpine east border, over the forested Carpathians and Wolhynien to Wolgaknie, near Kasan.

(3) With the beginning of the re-warming at the end of the High-Glacial phase and in particular the Late-Glacial the humidity relations of central Europe quickly again approximated those of the present. The ground frost disappeared, the forest covered the tundra

soil and also part of the southeast European steppe soil; with some retardation with respect to temperature increase, the ice sheets also disappeared, the ocean penetrated in stages to its present coasts, and the Baltic sea basin came into existence. Loess deposition abruptly ended in central Europe at the moment of the first ice retreat from the Brandenburg to the Frankfurt morainal stadial, for all young moraines and the Niederterrassen of central Europe (perhaps with the exception of some very special, locally bounded occurrences), are free of loess.

High-Glacial and Late-Glacial are thus separated from one another by an especially sharp climatic change.

The loess dust, with its diameter of 0. 2-0. 02 mm, is a product of great, repeatedly reworked gravel fans and valley bottoms of the Pleistocene tundra climate, not only the glacial but also all the non-glacial valleys, including the uppermost dells. Certainly in the Early Glacial the loess dust had already been blown out from these surfaces. The distinction is that the conditions for loess deposition did not then exist in the vicinity of these valleys. This appeared general, in several phases, for everywhere in our loess regions the Early-Glacial solifluction lies at the base of the loess; then follows a transition zone with alternate deposition of solifluction loess and slope-wash loess, and on this the true eolian loess. Probably the drier (and perhaps even somewhat warmer) summer of the continental High-Glacial thus had a double effect: first the reduction of the water saturation and thus the movement of solifluction, and second a thicker tundra vegetation. Both favored the deposition of the loess dust, now increasingly deflated because of the longer dry periods of the non-glacial rivers. The polar boundary of its deposition, which in central Europe is associated quite sharply with the line Dünkirchen-Wesel-Osnabrück-Hanover-Magdeburg-Breslau-upper Weichsell, thus expresses at the same time the polar boundary of a densely grown tundra type restricting soil movements. South of this polar boundary lies the loess-tundra -- like all climatically determined vegetation zones -- a significant height boundary which rises to the northern edge of the Alps and of the French Central Plateau up to about 650 m. Above this boundary remain the heights of the Mittelgebirge in the range of the frost-rubble tundra, whereas the lower basin situations of northern France, central and southern Germany, as well as Galicia and the entire southeast European lowlands, now fall in the range of the loess tundra or loess steppe and thus were in regions of loess sedimentation.

In these low locations loess deposition certainly had increased morphologic effects. In the loess tundra it reached thicknesses of several meters, in the loess steppe sometimes thicknesses of several tens of meters. It may have covered the land in an almost complete blanket. Thereby the landscape, molded by strong denudational processes in the Early-Glacial, became already fossilized in the High-Glacial. Soil flow came to rest on all the more gentle slopes. With greater loess thickness even the smaller dells were covered with loess, which was only possible when the movement of solifluction rubble streams came to a standstill. In the driest locations in the south-German basin, in Rheinhessen and Rheingan, in Elsass and Kaiserstuhl, but also in the lowest parts of Neckar Schwabia and Mainfranken, the loess cover was often so thick that the old dells were completely filled; and the Early-Glacial terrain was thus lost under the loess cover. Occasionally relief inversion even occurred. This is found to the greatest degree in the Ukraine. Here beside the great rivers there occurs not only no Early-Glacial terrain under the loess cover, but scarcely even any High-Glacial; and on it -- partly in the Late-Glacial, partly in the Post-Glacial -- a very distinctive system of denudation forms has been developed: that of the Balkas and Owragi, which belong as the typical land form phenomena in the modern steppe climate of this region.

These very thick loess covers moreover, originated not only in the Würm glaciation. In the lowest parts of the south-German basins several loesses were deposited on one another, the lower originating in the earlier cold phases. They are separated by weathering horizons which relate to the moister climate of the interglacial warm phases. It is noteworthy, however, that above each of such warm-phase soils there immediately follows a solifluction zone (consisting at least of flow-loess if not of coarser solifluction material from the slopes above) and then the true eolian loess of the next cold phase. This leads to the assumption that the climatic succession inferred for the Würm in our region was recognizable also for earlier glaciations: cold-oceanic Early-Glacial and cold-continental High-Glacial. The work carried out from different points by Freising [18], Weidenbach [17], and myself [16] have led to an extensive understanding of this. The similarity already mentioned above for the character and course of the climate of the separate cold phases is therefore newly emphasized, and points to the similarity of the climatic course of the warm phases in striking parallelism, as known earlier by pollen analysts.

The central and southeast German loess is confined to the above-bounded region and is related solely and with great sensitivity to the climatic characteristics of the continental High-Glacial: we have already emphasized that loess deposition ceased with the very first

climatic swing to the Late-Glacial, at the very first retreat of the glacier. The glacial gravel spreading ceased; and the non-glacial followed soon after. Damper climate and denser vegetation soon stopped new loess formation in this entire region. It has been affirmed, on the other hand, that loess formation persisted in central Europe continuously until well into the Late Glacial and even occurred principally in this phase, thus to be misplaced in the last, cold, retreat episode of the younger Tundra phase. Opposing this, however, is the significant fact (already mentioned above) that all deposits of the High-Würm and the Late-Würm, including all High-Glacial moraines, gravel deposits, and Niederterrassen (glacial as well as non-glacial) are free of loess in the prescribed area everywhere (except for several really insignificant, unclear relic occurrences). The loess covers here lie only on deposits older than Würm High Glacial, and especially on those of the older glaciations. Moreover, Schonhals found, north of the defined central European loess region, several isolated, spatially delimited loess patches on the young moraines of Brandenburg and Lettland [19]. These show that here in the vicinity of the ice border which had already withdrawn far to the north, loess was revived locally at several favorable points and at a very different geographic range during the Late Glacial. In the Holocene, the European glacier finally shrank to the Greenland ice sheet and the recent highland glaciation. Here the glacier zone is surrounded everywhere by a small border of tundra-type climate above the forest border. And in some areas of this modern tundra zone, in the upper Wallis and in the background of several deep Icelandic and Greenlandic fjords valleys -- there occurs even today a reduced loess formation. Finally, in the vicinity of the present great, dry deserts--the North African and the Inner Asian -- loess is still formed. But all this seems far from the fossil loess region of central Europe, whose last time of growth lay distinctly in the High-Glacial of the Würm cold phase. A calculation of the entire volume of the High-Glacial Würm loess in Europe west of the Volga gave the sum of about 3000 cubic km! The Late-Glacial loess in Europe must at best amount to 1-3 cubic km, the entire Holocene only a fraction of one cubic km. Thus one can only then make the comparative statement that the loess in Europe is Late-Glacial as well as High-Glacial if he considers fully the quantitative side of the problem as well as the geographic, according to the former place of loess formation in the High-Glacial, Late-Glacial, and Post-Glacial.

IV. The Relic Forms of the Subtropical and Marginal Tropical Climatic Zones of the Würm Cold Period in Comparison with the Morphological Effect of the Present Climate in these Regions

In the whole Würm tundra region north of the Alps, we live today extensively in a fossil landscape of the cold period, which the weak geomorphic processes of the post-glacial were able to annihilate to a very small degree and replace with the forms of the present climate. In the Mediterranean region, however, the proportion of the production ability of the former and present processes is reversed. In the countries of the western Mediterranean basin the following picture is approximately presented: In southern France and even in the north Italian coastal region especially on "frost-susceptible" soils, forest-tundra type formations with clear solifluction phenomena extend locally down to sea level (the southernmost occurrences known to me are in the latitude of Livorno). Partly north of, and everywhere south of this latitude, however, the lower elevations of the Mediterranean were already forest land during the cold period. In northern Italy a subpolar pine-birch forest prevailed, in central and southern Italy a deciduous forest of the modern, central European; in North Africa followed the transition to the present Mediterranean type of forest.

For our problem, we must distinguish between this forest and the forest-free regions above the former forest boundary. This boundary lay in Corsica at only about 500 m elevation, and climbed to about 1200-1300 m in southern Italy and North Africa. Above this boundary, on the heights of the south European mountains, we still find today a fossil Pleistocene landscape with old cirques, moraines, solifluction covers, and broad Pleistocene terraces as in central Europe. Except the loess no longer occurs in the general Mediterranean region; for here not only was the high -glacial dry period lacking, but in the southern part of the Mediterranean region there was a general transition from the non-tropical region, which--as we saw above -- was on the whole drier in the Pleistocene than today, to the tropical region, which under the influence of the Pleistocene cooling received more humidity than at present.

In the lower areas of the Mediterranean region under the Pleistocene forest border the relations are very different. In the former Pleistocene forest region the climatically regulated geomorphic processes could attain no greater effectiveness than in modern central Europe. Here also, all relic forms of a Pleistocene tundra climate are lacking: fossil solifluction covers, dells, and river terraces. Today, there prevails in this climatic zone the open woods of the summer-dry Mediterranean climate with its catastrophic high water in winter. The forces of slope and valley erosion have therefore been strengthened here by the forest cultivation periods extending back thousands of years. The question is that here we

see the landscape exhibited especially through the geomorphic processes of the present climate: by the Frane denudation and the Calanche erosion on slopes, by the broad, recent torrent beds in the river valleys, and on limestone by the strong and clearly recent karst forms of the Mediterranean climate.

In the northern part of the Mediterranean region the lower height zone, in which the role of the Pleistocene and recent form elements of the landscape are reversed in this manner, is, of course, still not very pronounced. Especially in regions with high mountains, which still supported a much broader zone of Pleistocene tundra climate above the Pleistocene forest belt -- as in Corsica -- all the larger rivers were so strongly supplied with debris that they produced very broad Pleistocene valley floors, even down to the mouths at the sea: floors which these valleys -- as in central Europe-show today in the form of extensive terraces. The typical terrace-free torrent valley is therefore confined in the northern Mediterranean to small rivers in the lower landscape regions which were as a whole forested in the Pleistocene. The dominance of forms originating in the modern climate over the relic forms of the Pleistocene first became general in the southern Mediterranean region.

South of the Mediterranean region is the great trade-wind desert belt of the Sahara with its somewhat more humid border zones: the Mediterranean desert-steppe and steppe in the north and the desert savanna and dry savanna on the south. Here occur mainly the cold-phase (pluvial-phase) relic forms which were again somewhat stronger than in the landscape of today. The climate of this zone was certainly on the whole somewhat damper during the cold phases than today. From these times have come the extensive lake terraces, lake sediments, and fossil debris flows on Inselberge, and especially the extensive river terraces in the desert mountains. To be sure, the predominance of relics of the cold phase in the modern landscape is not so easily perceptible and not so generally distributed as in central Europe, and among all the forms of the modern landscape, is not explained clearly everywhere -- whether they originated in the maximum cold phase, in the recent climate, or in some special climatic type that came to prominence in the course of the late-glacial or the Holocene climatic fluctuations and developed an effective type of form due to some special characteristics. Among the latter forms probably belong the extensive old dunes in the Sahara and in the adjacent southern border zone of the Sudan, which I have classified as sub-recent forms from an early Holocene climatic phase.

According to the circumstances, whether the cold climate prevailing there formerly developed a dominant -- qualitative and quantitative -- effectiveness in a distinct landscape belt, or whether the geomorphic processes controlled by the climate of the Holocene were so strong that they could dissolve and superimpose the old relic forms, we find on the present land surface either regions in which the Pleistocene forms prevail, or those in which the recent forms prevail. Figure 3 is a first attempt to show the prevalence of one or the other group of forms in a meridional belt from pole to equator. It is obvious that our present inadequate knowledge concerning the separation of these different kinds of forms, requires much correction; there can thus be offered here only a preliminary, strongly generalized picture (see Figure 3).

Beginning from the pole down to an average latitude of 77°N we are today, as before, on glacier-covered land. The processes of gradation therefore have remained the same since the last cold phase. This is designated here by striping of the middle column.

Between 77° and 74° Lat. we are in the frost-rubble zone today. Its morphologic imprint is so strong that here all Pleistocene remnants have been completely destroyed. To a lesser degree this is the case in the range of the present tundra zone between about 74° and 69° N. Lat. This is shown in Figure 3 by a widely spaced striping of the right-hand column.

In the zone of the temperate forest, in the present non-tropical zone between 69° and 45° N. Lat., on the other hand, we encounter the dominance of Pleistocene landform remnants in the present landscape, as discussed extensively in Chapters II and III (narrow striping on the left column). A slight dominance of cold-phase landforms are also found in the northern part of the Mediterranean region, at least at higher elevations (see above), as is represented by wide striping on the left column between 45° and 40° N. Lat.

On the other hand, recent landforms prevail throughout the southern Mediterranean region (narrow striping on the right side between 40 and 35° N. Lat.), whereas in the dry belt bordering the equator (between 35° and 12-15° N. Lat.) one must probably consider a slight prevalence of fossil cold-phase forms on the average, although here in many places, the old and new forms are balanced, the recent forms sometimes even dominating, e. g. in young dune regions.

In the seasonally humid zones of the inner tropics (in Africa between 10° and 15° N. Lat.) an even stronger similarity between cold-phase and recent landforms is found; but the more similar they become the more difficult they

are to differentiate. Finally, in the rain forest of the inner tropics, as already noted, distinction between cold-phase and recent landforms is no longer possible with our present means. In Figure 3 this is designated by striping in the middle column; and this symbol is extended into the region of the seasonally humid tropics -- to 12° N. Lat. -- to indicate the general transition to the dry belt with the slight prevalence of cold-type forms.

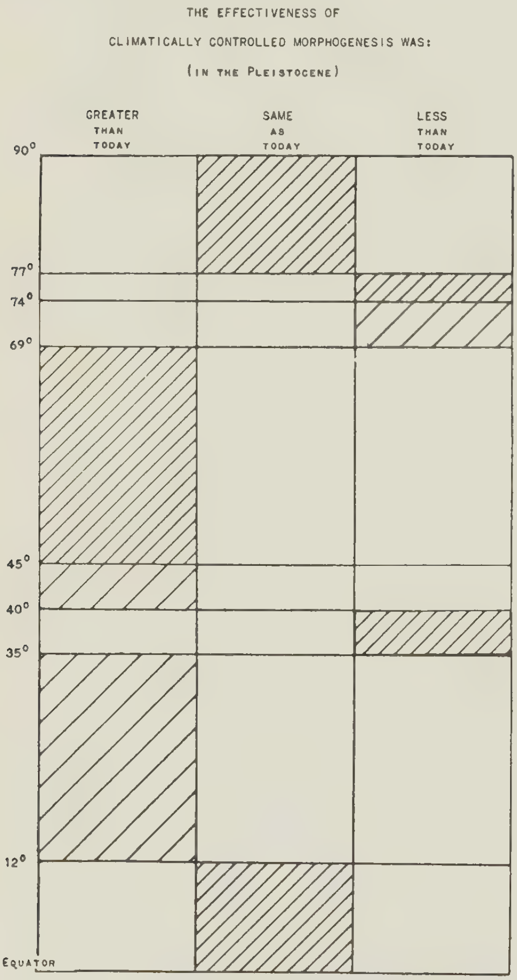


FIGURE 3. Dominance of Pleistocene relic forms or present-day forms in the climatic zones of the Earth (northern hemisphere, meridian range between 10°W and 35°E), where the climatically controlled morphogenesis in the Pleistocene was greater than today, Pleistocene relic forms dominate (left column); where it was less in the Pleistocene climate than today, modern forms prevail (right column).

As Figure 3 shows, the most poleward and most equatorward climatic zones of the present thus reacted least to the Pleistocene-Holocene climatic change: the former under the persistent cover of perennial ice, the latter under the scarcely changed mantle of tropical rain forest.

V. The Cold Phases in the Inner Tropics

Although the constantly humid rainforest of the tropical lowland left behind no recognizable morphological traces of the Pleistocene climate, the seasonally humid tropical lowlands (the savannas and monsoon forests) -- already much more extensive -- provide an abundance of cold-phase forms. I have carried out investigations concerning this in two journeys (1950/51 and 1953) into north-equatorial Africa, which lends itself to this by its uniquely regular arrangement of climatic belts: almost parallel to lines of latitude.

Previous investigations concerning the "Tropics" in the Pleistocene naturally proceeded from methods of Pleistocene investigation proven in the non-tropics. Thus on the whole six approaches have been pursued.

(1) Investigations of tropical deep-lake sediments. These have been especially involved in the classification of the Pleistocene -- like the corresponding profiles of the non-tropical ocean bottoms. We shall consider these further below.

(2) Investigations of the Pleistocene eustatic sea-level fluctuations: the strand terraces and the coral-reef problems. Although these formations influence the morphology of many tropical coastal areas, they result from purely non-tropical effects of the Pleistocene climate -- the change in mass of the great polar ice caps -- and they have no effect on the cold-phase climate of the tropics.

(3) Investigation of the present and Pleistocene glaciation of tropical mountains, which are confined heretofore to recent occurrences.

(4) Investigations are extended on the "periglacial" forms of the tropical high mountains between the upper forest and snow line [3]. In Ethiopia (Semien Highland, High Somolien) beyond the cold-phase snowline, which was just over 4, 000 in elevation, I tried to determine the lower boundary of fossil cold-phase solifluction phenomena: it lay about at or somewhat below 3, 000 m.

(5) The two last-named methods have yielded to Pleistocene research very reliable results concerning the already mentioned measurement of the cold-phase temperature depression in the tropics of 4-5°C. The theoretical calculations of this cooling by Flohn [2] indicated the same result. We thus recognize that this slight temperature depression (i. e. on the average for the tropical lowland climate of today about +24° to about 20°) scarcely

changes the character of the vegetation zones there, especially of the rain forest. Therefore with the last-named methods one can include only the fossil forms of very small tropical area -- the elevation zones above 3, 000 - 4, 000 m. -- but not the expanses of the tropical lowlands.

(6) As a separate Pleistocene phenomenon of these lowlands, there were investigated former lake-level fluctuations, especially undrained, inland lakes. They are designated as results of pluvial phases; and many investigators, like Nilsson in East Africa [20], believed it was possible to establish in the rhythm of these fluctuations a complete agreement with the rhythm of the non-tropical glacial phases. In the lakes of Ethiopia I found these results not confirmed, however: in the level of Tana Lake and the lakes of the Abyssinian trough, scarcely any such fluctuations can be recognized. Inasmuch as these lakes, according to my investigations, all result from the youngest volcanic formations of the country (late or post-Pleistocene), traces at least of the older Pleistocene climatic fluctuations are not to be expected in them. There remains to be explained whether older lakes of the inner tropics actually show such a clear rhythm caused by Pleistocene climatic fluctuations; at least for the humid portions of this zone this appears improbable to me. Conclusions on the climatic-morphologic effects of the Pleistocene climate in the tropics that interest us here do not themselves permit recognizable lake -level fluctuations.

In order to reach such results I have tried, from fossil soil covers and from the erosional and depositional forms accompanying them, to gain a picture of the cold-phase landscape of seasonally humid tropics [21]. This presumes a knowledge of the present zones of soil formation and morphogenesis in the present climatic zones that so far was lacking. Thereby it is shown that in fact, each of the present great climatic zones of north-tropical Africa corresponds to a definite climatic soil type and with it in association, a definite type of climatically significant morphogenesis. We thus find:

in the full deserts, the local type of gravel desert (desert payment soil), which changes according to geologic substratum, and the sand deserts (dune field).

in the desert-, shrub-, and dry-savanna, a succession mostly of bright-colored cohesive soils together with typical assemblage of forms of the "sheetwash zone".

in the humid savanna, the brightly colored tropical red loams often with a cell-like breccia structure associated with a very similar landscape. The latter soils extend to only about 2, 500 m. elevation in Ethiopia. Above, in a climatic zone prevailing up to the upper forest boundary at 4, 200 m. it is thus principally as far as vegetation is concerned.

in the high forests of the Dega zone, deep and easily flowable black soils to which is related a climatically controlled group of forms slightly departing from the sheetwash zone.

Nearby, in all these climatic zones are found partly fossil soils and fossil remains which resulted from a previous climate of a clearly different type. And generally there were remnants which imply a former humid climate. While in the non-tropics the strong cooling almost alone caused the very drastic displacement of all the climatic belts, in the tropical lowland exclusively, the increased humidity of the cold climate produced the structural changes of the climatic-morphologic zones; here relatively small.

Thus the remnants mentioned often permit the recognition of a multiple change from dry to humid phases. On different grounds, expressed in other places, one can, moreover, correlate with certainty the generally best expressed last one of these humid phases with the last cold phase, i. e. the Würm. But it is for the time being completely impossible to correlate one under another the effects of older pluvial phases occurring today in different profiles, or to compare them even with non-tropical Pleistocene effects. This will be possible only if we provide the succession of tropical humid phases with an observation much deeper and freer of gaps than today. Therefore in the foregoing we have consciously confined ourselves to a presentation of the Würm relations.

On the other hand, in the previous literature concerning tropical pluvial phases - based especially on a study of the fluctuations of sea level and lake level - their correlation with the non-tropical Pleistocene succession plays a great role. Besides the cited deficiency of our observations, such a procedure is also inadmissible because we still draw no complete picture of the glaciations in the non-tropics: there is thus measured here an indefinite time sequence with an even more indefinite measure. Only for the two last phases of glaciation do we stand today on sufficiently safe ground; and as far as this is actually the case, in contrast to a broad previous view, it is presented in the following.

VI. The Climatic Phases of the Würm

It was shown in an earlier work [16] that the present classification of the Würm extensively presented in the literature as three separate phases: WI, WII, and WIII, goes

back to an incorrect correlation of the loess zones of central Germany with the supposed Würm ice-border positions of northern Germany. These ice-border positions, moreover, encompass considerable portions of the older moraines. Weidenbach [17] later showed that an entirely similar confusion occurred in the correlation of the younger south-German loess zones with Würm and Riss moraines of the Rhine glacier. Thus the Riss loesses are correlated with the Würm complex; and the Soergel-type classification of the remaining Pleistocene shows thereby the three Würm phases mentioned. The tripartition of the Würm appears to him to correspond with the well-known radiation curve of Milankovitch. Soon after, Eberl and Knauer utilized the same designations WI, WII, and WIII in the classification of the Würm moraines, but without making a reference to the loess phases for which these designations had been coined. A second, more serious confusion in this matter thus led to the consideration of outwardly comparable but internally unrelated termini as synchronous and identical. Since that time, all over the world, an infinite number of phenomena, of which the assignment to the younger Pleistocene is established only very generally, have been forced into this scheme of a tripartite Würm, without an association of these phenomena with the true Würm deposits of Penck being established, or even attempted. One might assume that, including the cases mentioned below, there have been designated today in the international Pleistocene literature about 10-12 basically different things with "Würm I". Its general meaning simulates a chronologic or stratigraphic correlation among these phenomena which does not exist and which must hinder and encumber further researches most severely.

The new classification of the Late Pleistocene proposed here does not harm the essential results of all these observations, but establishes for several of them by a simple renaming, the relation, already clear today, to the true Würm deposits.

This new classification is expressed in a schematic curve of the central European climatic development since the end of the Riss glaciation (Figure 4). Corresponding to our present knowledge, it expresses the Würm as an undivided cold phase which, with the characteristic development repeated in Figure 2, tends to a single low point -- the loess phase of the Würm high-glacial time. The climb from this low point to the temperature level of the Post-Glacial results in small waves which correspond to the Late-Glacial retreatal phases of the glacier. Surely the earlier climatic development also ran in similar waves. But the uniform course of the Würm climatic curve was not distorted by this. A somewhat stronger such wave is situated in the end of the Late-Glacial in the Allerod or Two Creeks interstadial. A similar fluctuation exists with the Zwolle stadial of the Dutch investigators at the beginning of the Würm cold phase. On the other hand, the "interstadial" within the Würm is hypothetical: According to Schaefer[22], in central Europe it led neither to forestation nor to soil formation, and thus offered no effective interruption in the Würm.

All moraines of this single, Würm cold phase are fresh, dotted with kettles, depressions, and lakes, and without heavy cryoturbation mantle. The associated terraces are al-

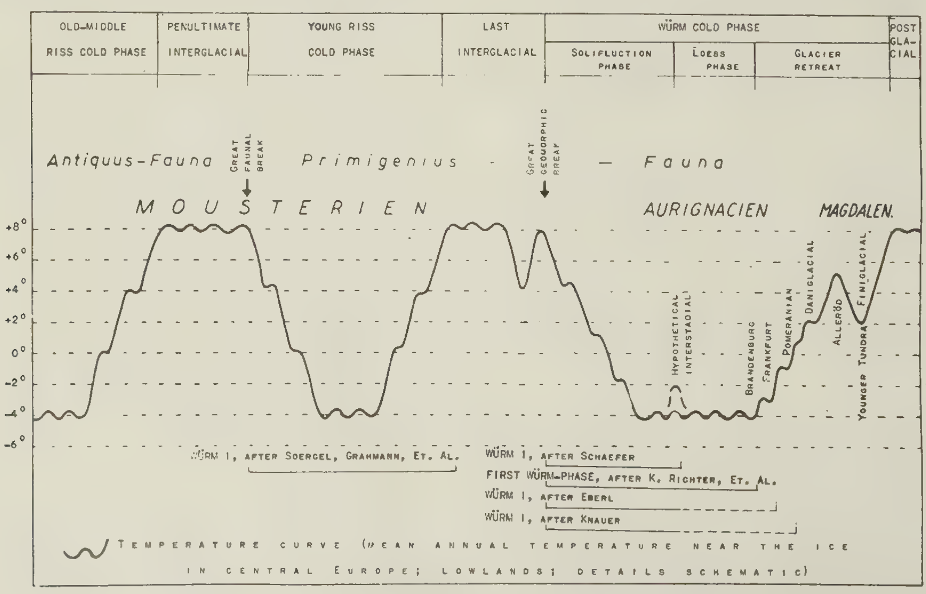


FIGURE 4. The climatic phases of the Younger Pleistocene.

most undissected and carry no loess. To this sharply demarcated glacio-morphologic complex Penck has confined the expression "Würm" But the same traits -- freedom from loess cover and fresh condition of preservation -- characterize also the entire province of Würm periglacial forms pictured above (section II), which prevail still today in degradation in central and western Europe.

From this, the next older cold-phase complex is clearly separated. The relief of its moraines is levelled in cases by strong cryoturbation and is without closed depressions, and without knobs and lakes, although on the whole the moraine ridges are still clearly recognizable. The terraces are broadly developed but are already clearly dissected. They are loess-covered, but they carry always only one loess, the only Würm loess that there is in fact: to this belongs the broad "valley-floor terrace" of the middle Rhine, and Graul's "Young Riss" terrace in the Alpine foreland. Penck had designated this morphologic complex as "Riss". I propose with Graul [23] and Weidenbach to call this peculiar cold phase hereafter "Young Riss", because meanwhile it has been shown that it is separated from the complex of earlier (middle and old) Riss deposits by a similar great warm phase as it is from the Würm cold phase.

This classification of glacier formations is dovetailed freely with those of the non-glacial deposits of central Europe. There is only one Würm loess -- that which contains traces of Aurignacian men, covers the Young Riss terrace as a single loess, and on older deposits is underlain by the "Göttweig soil" according to Freising [24], i. e. the weathering horizon of the last interglacial. The next older loess, on which the Göttweig soil originated, corresponds to the Young Riss glaciation; the deeper "Krems soil" at its base, which covers the older loesses, is the weathering horizon of the next-to-last interglacial. In similar ways, many other Pleistocene formations may also be fitted into this classification without prejudice to their essential basis, as paleontologic and prehistoric stages, sediments of depressions and lakes. Thus the great change in the late Pleistocene faunal development occurred before the Young Riss glaciation. Still not fully clear is the position of the Eem deposits in this classification; probably it belongs in the next-to-last interglacial.

Finally, Figure 4 shows which different sections of this classification have been designated as Würm I by several authors. Soergel and Grahmann apply this expression to the Young Riss. Others, like Schaefer, understand it as the first phase of the true Würm (from the last interglacial to the hypothetical interstadial mentioned). Eberl and Knauer advocate similar views, whereby they correlate with this Würm I the definite Würm moraines until now designated as retreatal stages. The first Würm phase (advance phase) has still another meaning, according to K. Richter [25]: it would encompass the entire Würm up to the first retreat from the Brandenburg stadial.

In contrast to this it is proposed:

(1) The designations Würm I, Würm II, etc., be stricken in the future as superfluous and erroneous.

(2) For the next-to-last cold phase the already introduced name "Young Riss" be retained,

(3) The Würm cold phase be correlated only with the morphologically clearly delineated complex of young Pleistocene deposits and certain contemporary phenomena. This complex is clearly separated from all older cold-phase traces in central Europe as much in glacial as in non-glacial regions. Moreover, in broad parts of the remaining world the climatic, pedologic, morphologic, and geologic traces of this last cold phase are certainly clearly understood.

REFERENCES

[1] Göhrs, I., DIE KLIMATE DER EWIGEN GEFRORNIS: Dissertation, Göttingen, 1951.

[2] Flohn, H., ALLG. ATMOSPH. ZIRKULATION UND PALÄOKLIMATOLOGIE DER ERDE: Geol. Rundschau, 40, 1952.

[3] Troll, C., STRUKTURBÖDEN, FROSTKLIMATE UND SOLIFLUKTION DER ERDE: Geol. Rundschau, 34, 1944.

[4] Wissman, H. v., ÜBER LÖSSBILDUNG UND WÜRM-EISZIET IN CHINA: Geogr. Z., 44, 1938.

[5] Büdel, J., DIE RÄUMLICHE UND ZEITLICHE GLIEDERUNG DES EISZEITKLIMAS: Die Naturwiss., 36, 1949.

[6] Frenzel, B., and C. Troll., DIE VEGETATION-SZONEN DES NÖRDL. EURASIENS WAHREND DER LETZTEN EISZEIT: Eiszeitalter und Gegenwart, 2, 1952.

[7] Richter, K., DIE STRATIGRAPH. BEWERTUNG PERIGLAZ. UMLAGERUNGEN: Eiszeitalter und Gegenwart, 1, 1951. Usually 50-60% of the stones in the solifluction covers are arranged according to the slope angle.

[8] Cailleux, A., MORPHOSKOPISCHE ANALYSE DER GESCHIEBE USW. Geol. Rundsch., 40, 1952, and Tricart, J., LA PARTIE ORIENTALLE DU BASSIN DE PARIS, II. L'EVOLUTION MORPHOLOGIQUE AU QUATERNAIRE: PARIS, 1952.

[9] Dege, W., WELCHE KRÄFTE WIRKEN HEUTE UMGESTALTEND AUF DIE LANDOBERFLÄCHE DER ARKTIS EIN? Polarforschung II, 1949, and further oral communication.

[10] Poser, H., and Th. Müller., STUDIEN AN DEN ASUMMETR. TÄLERN DES NIEDERBAYR. HÜGELLANDES: Nachr. Ak. Wiss. Gottingen, Math. -Phys. Kl., 1951.

[11] Büdel, J., DIE MORPHOLOG. WIRKUNGEN DES EISZEITKLIMAS IM GLETSCHERFREIEN GEBIET: Geol. Rundsch., 34, 1944, and Maárloveld, G. C., DE ASYMMETRIE V. D. KLEINE DALEN OP HET NOORD. HALFROND: Tijdschr. Ned. Aardrijkskund, Gen. 68.

[12] Mensching, H., DIE ENTSTEHUNG DER AUELEHMDECKEN IN NW-DEUTSCHLAND: Proc. III Cong. Sedimentology, Wageningen, 1951.

[13] Menching, H., SCHOTTERFLUREN UND TALAUEN IM NIEDERSÄCHS. BERGLAND: Göttinger Geogr. Abh., 4, 1950.

[14] A very similar sequence of valley formations phases also appears to exist in our Alpine rivers, whose Niederterrassen certainly originated in the glacial rivers of the Würm glacial phase. Their different stages usually run together at a certain distance from the glacier border into a single "Hauptniederterrasse." Most recently Graul on the lower Iller found that here at a still greater distance from the glacier margin a younger erosion phase cuts the Hauptneiderterrasse and lies several meters deeper; whereupon, (in fact in the Bronze Age), still a younger alluvial fan was spread over the whole. I suppose that the Illertissen level (like the lower Niederterrasse of the Weser) should be put in the Late-Glacial, but that the Bronze Age alluvial fan (like the floodplain loam cover of the Weser) should be ascribed not to a natural climatic fluctuation in the Bronze Age but to the contemporaneous first great deforestation by man. Their erosional products must naturally acquire coarser grain size in the Alpine foreland than in the highlands or Mittelgebirge. (Literature basis: Graul, H., and Groschopf, P., GEOL. UND MORPHOLOG. BETRACHTUNGEN ZUM ILLER-SCHWEMMKEGEL BIE ULM: 5 Ber. Naturforsch. Ges. Augsburg, 1952).

[15] Büdel, J., DIE MORPHOL. WIRKUNGEN DES EISZEITKLIMAS IM GLETSCHERFREIEN GEBIET: Geol. Rundschau, 34, 1944.

[16] Büdel, J., DIE KLIMAPHASEN DER WÜRMEISZEIT: Die Naturwissensch., 37, 1950.

[17] Weidenbach, F., GEDANKEN ZUR LÖSSFRAGE: Eiszeitalter und Gegenwart, 2, 1952.

[18] Freising, H., NEUE ERG. D. LÖSSFORSCHUNG IM NÖRDL. WÜRTTEMBERG: Jh. Geol. Abt. Würrt. Stat. L. A., 1, 1951.

[19] Schönhals, E., SPÄTGLAZIALER LÖSS IN LETTLAND: Neues Jahrb. f. Mineralogie usw., Monatshefte 1944 B.

[20] Most recently in Nillson, E. THE PLUVIALS OF EAST AFRICA: Geografiska Annaler, 1949.

[21] Büdel, J., BERICHT ÜBER KLIMA-MORPHOLOGISCHE UND EISZIET-FORCHUNGEN IN NIEDER-AFRIKA: Erdkunde, VI, 1952. Also: PROBLEME DES PLEISTOZÄN IN AFRIKA: Vortr. IV Int. Quartärkonforenze, Rom, 1953.

[22] Schaefer, I., ZUR GLIEDERUNG DER WÜRMEISZEIT IM ILLERGEBIET: Geologica Bavarica, 18, 1953.

[23] Graul, H., ZUR GLIEDERUNG DER WÜRMEISZEIT IM ILLERGEBIET: Geologica Bavarica, 18, 1953, and numerous earlier works.

[24] Freising, H., NEUE ERGEBNISSE DER LÖSSFORSCHUNG IM NÖRDLICHEN WÜRTTEMBERG: Jh. Geol. Abt. württ., Stat. L. A., 1, 1951.

[25] Richter, K., KLIMATISCHE VERSCHIEDENHEIT GLAZIALER VORSTOSSPHASEN IN NORDDEUTSCHLAND: Vortr. IV Int. Quartärkonferenz, Rom, 1953.

SOME QUESTIONS RELATED TO THE FORMATION OF OIL STRUCTURES IN APSHERON[1]

by V. S. Melik-Pashayev

translated by S. Faizi

The productive sequence in the Peninsula of Apsheron is one of the richest oil-bearing sedimentary successions known in the entire world. It is rich because of the oil content in many beds and the highly favorable physical properties of the reservoir rocks. The largest number of oil-bearing beds is confined to the eastern part of the peninsula, where the largest structures have dozens of oil-bearing groups (Balakhany-Sabunchi-Ramany, Surakhany, Kara-Chukhur, Bibi-Eibat, Kala, and others). The islands of the Apsheron Archipelago also have structures with substantial reserves of oil (Island of Artem, coast of Darwin, Gyurgany, Neftyanye Kamni, and others). There are less rich regions in the western part of the peninsula (Shabandag, Kergez, Shongar, and others). The richness of the deposits decreases sharply due north; within the limits of the structures of Kyurdakhan, of the bank of Apsheron and in the uplift of Mardakyan, no oil traps of economic value have been found. The upper and middle parts of the productive sequence show sharp differences in bedding, forms of occurrences, and quantity of oil throughout the oil-bearing area of the Peninsula of Apsheron. The oil and gas structures in the region of Apsheron can be, according to the circumstances of their information, divided into:

(1) Those controlled by structures which include oil-and gas-bearing beds in the crest of folds and tectonically terminated deposits.

(2) Those controlled by lithology, which, according to M. F. Mirchink, include structures confined to zones where oil-bearing beds die out or where the beds change lithologically, passing into impermeable rocks.

STRUCTURALLY CONTROLLED DEPOSITS

Deposits at the Crest of Folds

The deposits in the upper part of the productive sequence represent are most characteristic of this type and occupy the most elevated parts of folds, being located symmetrically on both sides of their axis (Figure 1). The boundaries of the oil-bearing area in the majority of cases follow the structure contour lines, being interrupted only by significant faults; but even then, as a general rule, the symmetrical position of the oil-saturated horizon remains preserved, although it becomes broken into a number of isolated blocks.

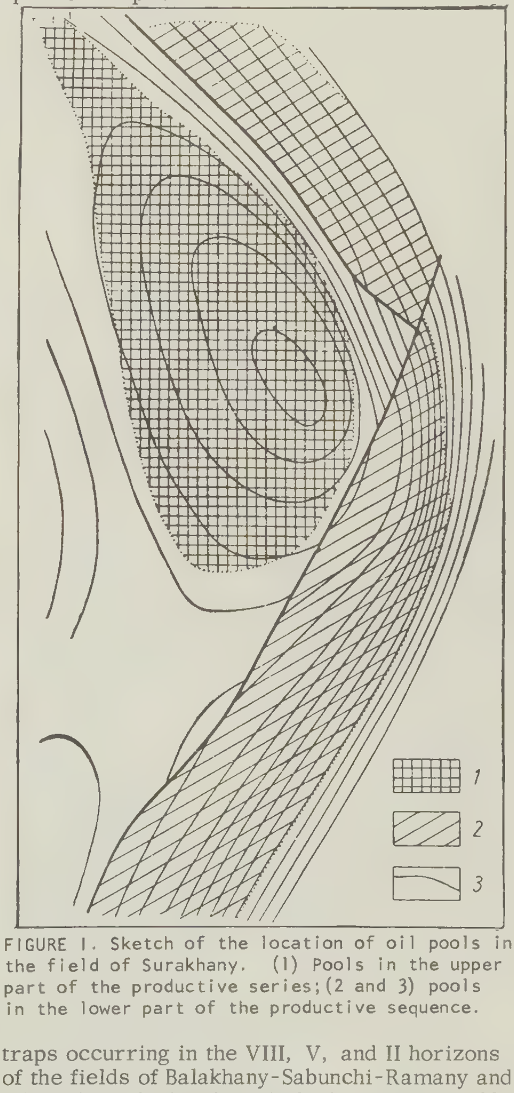


FIGURE 1. Sketch of the location of oil pools in the field of Surakhany. (1) Pools in the upper part of the productive series; (2 and 3) pools in the lower part of the productive sequence.

The second peculiarity of this type of closure is its relatively small height. Except for the traps occurring in the VIII, V, and II horizons of the fields of Balakhany-Sabunchi-Ramany and Bibi-Eibat, the heights of which vary from 200 to 350 meters, all other traps are within the heights of 50 to 100 meters. The width and

[1]Nekotorye voprosy formirorany neftyanykh zalezhey apsheronskoy neftenosnoy oblasti. Sovyetskaya geologiya, 1958. No. 4, pp 124-143.

length of these structures reaches 1. 2 and 3. 8 kilometers respectively. The majority of the traps, both across and along the strike have equal heights. The so-called "sliding" of traps in overturned folds may be observed in some horizons in the fields of Balakhany and Bibi-Eibat

The symmetrical location of oil-bearing beds at the crest of anticlines is related to the secondary origin of oil-bearing beds in the upper part of the productive sequence.

As a result of tectonic studies of oil traps in the Peninsula of Apsheron, a system of faults dying out in depth was established in the upper part of the productive sequence. These faults are, in the majority of cases, normal to the axis of folds and confined to their central parts.

The study disclosed that these faults are a prime controlling factor in the distribution of oil. These cracks are the channels along which oil ascends from the lower to the upper part of the productive sequence. Since the disturbances are confined to the crest of anticlines, it is natural that the traps become confined to the most elevated parts of oil-bearing structures.

The formation of traps in the upper part of the productive sequence as a result of vertical migration along the fault planes is confirmed by the fact that despite the sharp increase in the thickness of beds due south, the occurrence of additional sand layers and the presence of all conditions required for oil accumulation, such deposits do not occur in the beds of the upper part of the productive sequence further south of the faults.

One more fact confirms the concentration of oil at the faulted crest of folds. In those structural forms where the crest of anticlines are eroded, the upper part of the productive sequence does not carry even traces of oil. If oil had migrated along the beds themselves, traces would have been preserved on the flanks of folds.

Consequently, the oil traps became confined to the crest of folds, and the erosion of the structure resulted in erosion of the deposit and its complete disappearance. As an example of the relation of oil distribution to faults, we may mention the oil trap of the second horizon in the field of Kala. This field is broken into separate blocks by a net of faults, and each of these blocks, regardless of their position in the structure, carries its own independent of gas sequence at the bottom of the block.

The study of the quality of oil also provides us with an irrefutable evidence of the secondary origin of oil structures in the upper part of the productive sequence.

The principal qualitative factors of oils are the specific gravity, benzine potential, and octane figure. Studies to this effect, particularly those carried out by B. M. Sarkisyan [24], disclosed that the specific gravity of oil in the upper part of the productive sequence, as a general rule, increases, with the depth of the beds and the benzine potential changes in the opposite direction. The highest benzine potential is in the horizon of the Surakhan formation and the lowest at the bottom of the Balakhan formation. The best example of the above statement is the trap in Surakhan. Here the specific gravity of oil gradually drops from 0. 872 in the IX sequence of the Balakhan formation to 0. 786 in the A and B sequences of the Surakhan formation, and the benzine potential rises from 4. 1 to 25. 3 percent respectively. Such a regular change in the specific gravity and benzine potential of oils permits us to assume that sublimation of oil, if the term can be applied in this case, takes place in the depths and sends the material upward until the light oil concentrates in an upper bed and the heavier in a lower one; as far as the upper part of the productive sequence as a whole is concerned, the oil in the Surakhan formation has the lowest specific gravity, the highest benzine potential, and does not contain mineral pitch.

The study of the physico-chemical properties of oils leaves no doubt that oil in the upper Surakhan formation,consisting exclusively of light fractions, is a product of sublimation of oils of lower horizons. This conclusion is also confirmed by the fact that oils of the upper part of the stratum, particularly of the horizons of the Surakhan formation, have the maximum octane figures.

It is know that selection of the lightest fractions increases the octane figure of a given oil. Consequently, it is completely natural that the light fractions with the highest octane figures would migrate vertically along existing zones of disturbance.

Thus the quality of oils also confirms the secondary origin of the oil structures in the upper part of the productive sequence.

Tectonically Terminated Deposits

While traps in the upper part of the productive sequence are located symmetrically at the crest of folds and differ only with regard to the extension of the oil-saturated areas, this is not the case in the lower part of the sequence (KaC and PK).[2] On the contrary, here another peculiarity is the case, namely, the location of oil traps beyond the crest of folds and, in a number of cases, the occurrence of one-sided, tectonically terminated oil structures.

[2] KaC = Kala formation; PK = Underkirmakin formation.

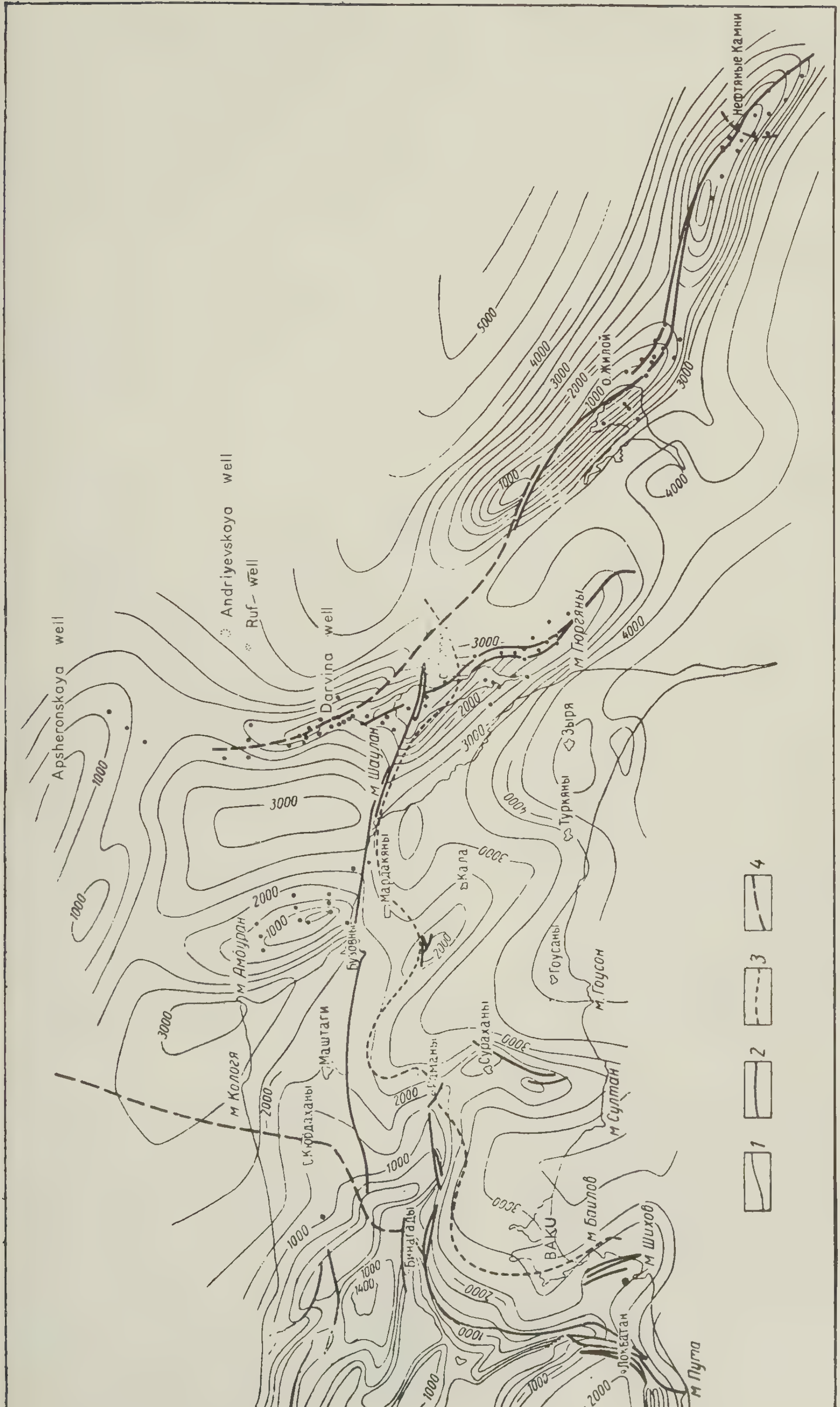


FIGURE 2. Structural map of the Peninsula of Apsheron and the Apsheron Archipelago; contour lines on the top of the Underkirmakin formation. (1) Contour lines on the top of the Underkirmakin formation, or of sediments underlying the productive sequence (if the Underkirmakin formation is absent); (2) Fault planes; (3) Boundaries of the extension of the Underkirmakin formation; (4) Boundaries of the extensions of the Kala formation.

The height of traps in the lower part of the productive sequence depends principally on the heights of folds themselves. Folds with the steepest flanks have the highest closure, for example, the fields of Binagady and Surakhany, where the height of closure reaches 700 meters. The plunging or gentle folds, such as in the Kala and Buzovny-Mashtagi fields, have oil structures at heights of 140 to 200 meters.

The height of closure in the PK layers is substantially greater in sections along the strike than in cross-sections. As has been noticed in a number of cases, traps slide in the plunging direction of folds. Especially pronounced examples of this were noticed in the Balakhany-Sabunchi-Ramany trap, where the differences in the height of closure in sections across the strike and parallel to the plunging axes of folds reach 2, 000 meters (Figure 6).

The structures of the lower part of the productive sequence in the Underkirmakin formation have greatest variety of form. This formation, in nearly all of the oil fields of the eastern Peninsula of Apsheron, have oil structures in only one flank, while the deposits in the Apsheronian Archipelago occupy both flanks of folds. In the Balakhany Sabunchi-Ramany structure, oil occurs in tne northern flank and is terminated by a fault trending latitudinally along the fold axis.

The structure in the PK formation is continuous for 9 kilometers. The depth of the oil-bearing sands increases along the plunging fold axis. As a result, the boundaries of oil saturation in the PK formation cut the contour lines sharply. The southern boundary of the structure coincides with a fault plane trending along the central part of the oil-bearing structure, while its northern boundary has a peculiar curved form causing variations in width.

Especially sharp changes in the width were established in the western part of the field of Ramany, where the oil-bearing structure broadens to 1,500 meters and then shrinks to 600 meters.

The axis of the same anticline within the Surakhany field trends from northwest to southeast and, in conformity with this, the trap in the PK formation is located in the northeastern flank of the fold in the two adjacent but tectonically separate fields: the northern and the southern. In both cases, the oil-bearing area is terminated by faults in the west. The width of the deposit in the northern field is 700 meters; it height does not exceed 400 meters, and the length is 3, 000 meters. The oil structures of the southern field of 800 meters wide, 550 meters high, and 3, 750 meters long.

The structures in the PK formation pass into the eastern flank of the uplift of Kara-Chukhur and, following its plunging axis, reach the coast at Zikh. It is interesting to note that the oil structure of Kara Chukhur, as in the previous case, is terminated by a fault trending along the eastern flank of the fold. The only difference in the position of this trap from the above case is in the south, within the Zikh field, where the displacement decreases, the trap strikes along the eastern flank without extending into the western.

Summarizing these facts, we may conclude that within the eastern half of the "half ring of Baku" (Balakhany-Sabunchi-Ramany, Surakhany, Kara-Chukhur), the structures in the PK formation are always terminated by faults and confined to one flank of the respective structures, the northern or the eastern.

The oil saturation in the PK formation within the field of Bibi-Eibat is confined to an arc-shaped uplift located east of the fold zone of Atashka-Lokbatan and separated from it by a small syncline along the valley of Yasamal. The deposit differs slightly from the above-described cases. Here the principal oil structure, terminated by a reverse fault, is 1, 000 meters wide and confined to the northeastern flank of a fold located under the sea; the northwestern plunging part of the fold is also oil-bearing, while its southern plunging part carries only small amounts of oil. The quality of the oil in the eastern flank differs sharply from that of heavy oils occurring in plunging parts of the fold. The oil saturation extends far behind the plunging parts of the structure. However, the western flank of the fold of Bibi-Eibat, like other structures in the Peninsula of Apsheron, does not contain any oil. The northeastern part of the Peninsula of Apsheron has an oil trap confined to the southern flank of the "structural nose" of Mashdagy and to the central and southern parts of the uplift of Buzovny. This trap trends continuously for 6 kilometers and is terminated by a latitudinal fault in the north. The gentle dip of the sequence indicates the presence of water below oil.

In the field of Kala, the oil structure in the PK formation is largely confined to the northwestern plunging part of a fold. Here, the width of the structure reaches 1, 500 meters, but it declines 500 meters further south. The structure is terminated by faults in the south and by a water-oil contact in the north. The height of closure does not exceed 200 meters.

The oil deposit in the PK formation of the northern anticline on the Island of Artem differs sharply from those occurring in the same formation within the Peninsula of Apsheron. The latter occupy only one flank of the respective structures, while in the northern anticline on the

Island of Artem the oil occupies both flanks, although more concentrated in the western flank. The difference in the productivity of the two flanks can be explained by lithological changes; the sands of the PK formation thin-out and are more fine-grained due east. The crest of the northern anticline is broken by a system of faults and fractures and saturated with water.

The oil saturation of both flanks of anticlines makes the structure in the Island of Artem wide; in its broadest part, between the two folds, it is 4 kilometers wide, but due south it decreases to 1.5 kilometers. In the south the structure is terminated by a major fault, which, in the form of a reverse fault, displaces the beds for about 150 meters in its northwestern part and "seals" the sands of the PK formation of the Pontus system. In its southwestern part, however, it becomes a thrust fault; the southwestern flank of the anticline thus overlies the northeastern.

After a short interruption, the trap appears again in the north in the structure of the Bank of Darwin. Here the oil saturation was established in the Kirmakin and Underkirmakin formations in the southern flank of a steep overturned fold. The deposit in the PK formation trends along the axis of the structure in the form of a 300-meter wide strip.

The southeastern plunging part of the same anticline has the trap of Gyurgyany-More, where the oil saturation of the PK and KC[3] formation is confined to the southwestern elevated flank and is terminated by the thrust fault which displaced this flank.

In the group of uplifts of the islands of Zhily-Neftyanye Kamni, the principal traps, confined to the southeastern plunging part of the structure of the Island of Zhily, occupies the southeastern flank of the structure below the thrust fault. However in the fault zone, drill holes recovered oil in the PK formation, both above and below the thrust fault. The structure of Neftyanye Kamni is remarkable because of oil saturation in the Kala, Underkirmakin and Kirmakin layers, both in the southwestern and northeastern flanks of the structure. The crest of the fold is saturated with water.

The further gathering of data will perhaps permit the distinction of oil- and gas-bearing beds confined to mud volcanoes. This is indicated by the fact that the mud volcanoes are not always located at the crest of anticlines.

The oil saturation in the Balakhany formations of the Zykh trap occurs at a substantial distance from the crest of the fold of Kara-Chukhur, beyond the boundaries of oil saturation of the same layers in other fields. Here the formation of the oil deposit in the upper part of the productive sequence is related to the buried mud volcano of Zykh, to which the trap is confined (Figure 3). The study of mud volcanoes in the archipelagos of Baku and Apsheron permits us to assume that further investigation may lead us to the discovery of a great number of new traps confined to active or buried mud volcanoes.

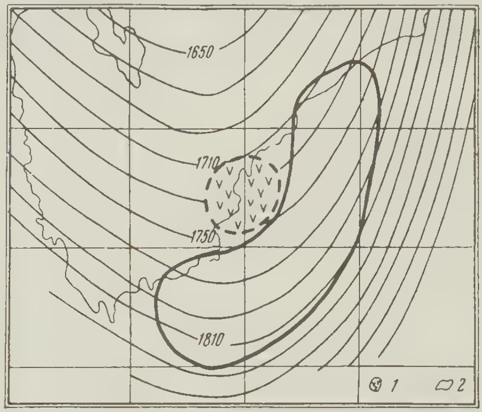


FIGURE 3. Sketch of the location of oil pools in the VIII horizon in the field of Zykh. (1) A buried mud volcano; (2) Oil deposit.

Lithologically Controlled Deposits

The deposits in the PK formation found in the structures of the western half of the "half ring" of Baku are of a quite peculiar type. The boundaries of the marine basin, in the bottom of which the PK formation was deposited, did not reach the axial part of the present anticlinal zone, and therefore, the sands of these layers remain restricted to the southern and eastern flanks of the oil-bearing structures. The oil traps being confined to a zone where the PK formation dies out, consequently are controlled by the lithology of the sediments depending on the above marine boundaries.

One of the uplifts within this tectonic zone, that of Binagady, trends latitudinally and joins the meridional anticline of Kirmaky in the east. The oil trap in the PK formation confined to the southern flank of this uplift extends into its northern flank only for a short distance. The deposit is from 600 to 700 meters wide in the eastern part and shrinks to 200 to 250 meters further west in the zone of steeply dipping beds, but then it broadens again, reachang 600 meters at its southwest end, where the beds gradually become gentle (in the field of Chakhnaglyar). About the same width is found on the eastern flank of the fold of Sulu-Tepe, except for its southern part, where the trap shrinks substantially.

It must be noted that this oil trap begins in

[3] KC = Kirmakin formation.

the extreme eastern part of the Binagady field and without any interruption extends along the strike of beds through the Chakhnaglyar field and dies out in the region of the Lake of Hoja-Hasan, where the oil-bearing beds change their strike in the structure of Sulu-Tepe. A remarkable peculiarity of the trap is this: the depth of the oil-bearing part of the bed increases from the average 700 meters in the Binagady field at the northeast to 1,300 meters in the field of Chakhnaglyar and 1,400 meters in the Sulu-Tepe field at the southwest; besides, the thickness of the PK formation decreases in the same direction from 20 meters in the field of Binagady to 6 meters in the field of Sulu-Tepe.

Thus the oil deposits in the PK formation of the above three fields can be united into a single structure of Binagady-Chakhnaglyar-Sulu-Tepe, for they have common conditions of sedimentation which caused the oil-bearing bed to pinch out.

South of Sulu-Tepe, in the valley of Yasamal, located in the eastern flank of the fold of Shabandag-Atashka, the pinching out of beds was also established (Figure 4). The deposit in the PK formation of the Yasamal field differs from those described above because of its small width, not exceeding 200 to 250 meters, and its deeper position (up to 1,800 meters). The oil trap is nearly parallel to the strike of the beds, but in the southern part of the structure it becomes deeper (2,000 meters).

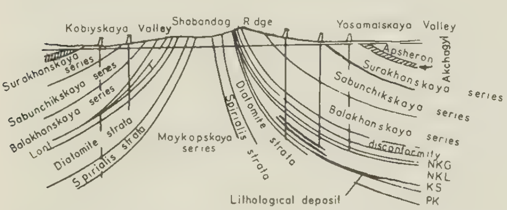


FIGURE 4. An oil trap in the Underkirmakin formation in the valley of Yasamal.

The exploration of the PK formation further southwest established their presence in the plunging southern flank of the anticline of Lokbatan and succeeded in finding powerful gas fountains coming from a depth of over 3,250 meters.

Thus the oil traps along the entire zone of the folded structures of Binagady-Chakhnaglyar-Valley of Yasamal-Lokbatan are confined to a belt where the PK formation pinches out; therefore the traps belong to the lithologically controlled type. The depth of the oil-bearing group in this zone increases gradually due southwest from 300 to 3,300 meters and the width of the zone decreases from 600 to 200 meters.

The underlying Kala formation, which begins in the plunging part of the fold structures of eastern Apsheron, also contains lithologically controlled oil traps. The traps under exploitation occurring in the Kala formation are located in the eastern plunging flank of the Surakhany and Kara-Chukhur anticlines, and in the southeastern plunging part of the Kala anticline (Figure 5).

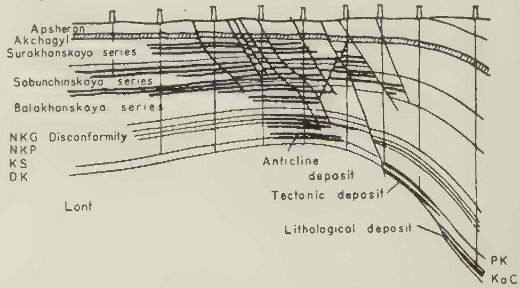


FIGURE 5. An oil trap in the Kala formation in the field of Kara-Chukhur.

The height of the lithologically controlled traps is substantially less than that of tectonically terminated ones, and does not exceed 400 meters within the Peninsula of Apsheron (200 meters in the field of Kala and in the Valley of Yasamal), and 400 meters in the Surakhany (KaC) and Chakhnaglyar (PK). The width of the lithologically controlled traps varies from 200 to 600 meters, and their length reaches 5.5 kilometers. As far as those lithologically controlled traps are concerned, where oil-accumulating beds pass into impermeable rocks, they rarely occur in the Peninsula of Apsheron. Traps which occur in certain parts of oil-bearing groups in the Kirmakin formation (Island of Artem and Bibi-Eibat), where sands are coarse-grained and highly permeable and consequently capable of releasing their oil content much more easily, may also be considered lithologically controlled, as may the oil traps in the Kala formation within the Gousany field.

The determination of the type of oil traps occurring in the Peninsula of Apsheron is very important for the selection of suitable locations for exploration and for planning drill holes. For example, the small depth of the traps confined to the crest of folds is a good basis for assuming that they can be formed even at gentle upwarpings of beds. This assumption makes it possible to look for oil traps within the submarine structures in the southern coastal belt of the Peninsula of Apsheron, for the plunging of folds due south and the more gentle dips do not exclude the possibility of economical oil recovery in the gentle folds.

The prospecting for tectonically terminated traps requires a detailed tectonic study of the lower part of the productive sequence and of

the directions of the lateral oil migration.

The lithologically controlled traps related to the pinching out of oil-bearing groups, having great lateral extensions along the strike and small width, require well-spaced drill holes along the strike.

"Hanging" Traps

It must be assumed that the oil formation in the lower part of the productive sequence followed tectonic processes which had produced plicative dislocations. At this time the oil traps were apparently located symmetrically in both flanks of the newly emerged anticlines. Further, strike faults in central parts of folds displaced one of the flanks relative to the other. In the eastern Peninsula of Apsheron and in the Apsheron Archipelago, mostly the eastern flanks of folds were displaced downwards, and the lower layers of the productive sequence became, therefore, "sealed" by the clays of the Pontus formation; the oil traps enclosed in the layers of the eastern flanks could consequently remain preserved.

An entirely different situation was produced in the western and southern flanks where the higher layers came into contact with the sand beds of the productive sequence. The pressure of surrounding waters caused the replacement of oil by water in the western and southern flanks of the structure, and the fault planes served as channels for the vertical migration of oil into higher groups.

Some geologists attempt to explain the one-sided or "hanging" position of oil traps as the result of certain peculiarities in the formation of the folds themselves. They believe that oil traps are confined to eastern flanks of meridionally striking folds because of the form of the original depressions of sedimentation which, according to them, were stair-shaped and generally had an easterly dip. Folds did not arise in the form of typical ranges, but like inclined terraces dipping easterly. Oil migrating along beds became accumulated east of the ledges. Then, as the folds received their final forms, oil could not enter the western flanks of the structures but became accumulated near the highest parts of the newly-formed uplifts.

I. I. Potapov believes that the so-called "hanging" oil deposits located themselves in zones of minimum thickness of the beds, and, regardless of the position of the latest folds, became confined to the crests of the oldest anticlines. This assumption contradicts many facts and distorts the actual causes of the formation of one-sided oil traps.

These old anticlines cannot be recognized in the present form of the structures. Besides, it must be noted that in the majority of those structures, where the "hanging" oil traps occur, terraces do not exist, and where they do exist they appear along plunging axes of anticlines far from the latter's crests. As an example, we may mention the oil field of Gyurgyany confined to an area with a gentle dip and located deep in the plunging part of the southern Artem anticline; the tectonic position of the oil fields of Zykh and Kara-Chukhur is also similar. Besides, according to I. M. Gubkin, the terrace-shaped ledges themselves are structural forms favorable for the formation of oil traps and there is no need to consider them as old arches.

In connection with his interpretation of the origin of "hanging" oil traps I. I. Potapov emphasizes the slight mobility of the "deposits of fluid oil" because of which the "hanging" deposits in the PK and KC formations could change their locations only slightly as they moved from their original positions into the crests of the latest anticlines. Actually, there are oil deposits in nature which became less mobile because of oxidation at their edges. However, it would be wrong to speak of the low mobility of oil just as an attempt to prove the location of oil traps at the crests of old anticlines. The majority of geologists consider the lateral migration of oil a significant factor in the formation of oil traps in the lower part of the productive sequence. V. A. Gorin points out, apparently with justification, that oil could migrate even from the South Caspian basin, which is very far from the present location of the oil traps. The exploitation of the same "hanging" oil traps gives us very convincing examples of the great mobility of oil. For example, the boundaries of the "hanging" oil accumulations in the PK formation of the eastern flank of the Bibi-Eibat anticline easily moves up-dip along the beds. The boundaries of the oil trap in the PK formation of the Chakhnaglyar field have moved with surprising speed, reaching 40 and even 100 meters a month in places, during the last five years; it reached the highest point in the deposit during a period completely incomparable with the length of a geological period.

Thus the mobility of oil in some "hanging" traps depends on the conditions existing in the oil-bearing group and on the grade of oxidation at their edges.

If we accept the statement by I. I. Potapov concerning the preservation of oil occurrences within old anticlines since their formation, we must inevitably agree that oil did not migrate from the lower part of the productive stratum at all, and, consequently, must doubt the secondary origin of oil traps in the upper part of the sequence which was proved in an excellent manner by I. M. Gubkin in the example of the oil traps of Baku.

The study of the extent and the directions of the regional underground oil migration is a very important part of the study of trends in the formation of oil traps.

The significance of the lateral migration has been widely discussed in the Soviet and foreign literature. I. M. Gubkin wrote: "... alteration of organic substances into oil under the influence of various factors begins as soon as these materials become buried in the sea bottom and continues through the entire period in which the buried substances sink gradually into deeper zones of the earth's crust with higher temperatures and pressure. As long as diagenetic alteration advances, the diffuse-scattered oil and accompanying gases move into sand beds. The formation of oil pools follows the formation of folds, when oil and gas, accumulated in sand beds above water, move from adjacent depressions into the highest points of tectonic elevation."

A. A. Trofimuk, describing the oil-bearing depression of the Volga-Ural as a tremendous territory bounded by the western slope of the Ural Mountains, the Volga River, the southwestern slope of the Timan Range and the northern edge of the Fore-Caspian Lowland, emphasizes the location of oil occurrences in the Paleozoic sediments and their close relation to the sediments of the Ural geosyncline. Considering the oil region of Ural Volga as a zone of oil formation of Paleozoic age, he assumes a lateral oil migration in this tremendous region for long distances.

A. A. Bakirov points out, with justification, that the territorial location and the structural relationship of large tectonic features of the Russian Plateau have been changed substantially during their geologic history. Some regional depressions of the Caledonian period became elevated regions during the next Hercynian orogeny, and this excluded the possibility of oil migration only in a single direction. He believes that the extent of regional oil migration on both plateaus and geosynclines is predetermined by the positions of large tectonic features and their structural relations in certain periods of geological history.

The lateral oil migration takes place, according to some geologists, within short distances. A. I. Levorsen believes that oil and gas may migrate for short and long distances depending on the location of a "trap" where oil and gas saturate permeable rocks.

A very interesting point of view was expressed by Sh. F. Mekhtiyev, I. S. Beiramov, and A. P. Ushakova, according to whom the oil traps in the PK and KC formations may be formed by hydraulic factors.

In recent years many facts were gathered in favor of the theory of long-distance oil migration as a result of hydraulic causes. One of these facts is the inclined instead of horizonal position of the oil-water and gas-water contacts in many deposits. The inclined position of these contacts was established in some traps in the Peninsula of Apsheron and is especially clearly expressed in the Underkirmakin formation within the Balakhany-Sabunchi-Ramany structure (Figure 6).

The inclined position of the oil-water contact, in places at a substantial angle to the contour lines of the structures, may be explained if we assume that the oil pool was previously strictly conformable with the oil-bearing bed but changed its position because of a later tectonic action. At the same time, oxidation and other alterations in the oil near the contact produced such conditions that the pressure of surrounding waters was no longer able to overcome the resistance and bring the pool in conformity with the bed. Thus, the oil pool could not take a new position conforming with the sharper pronounced anticlines. This is the cause of the inclined position of

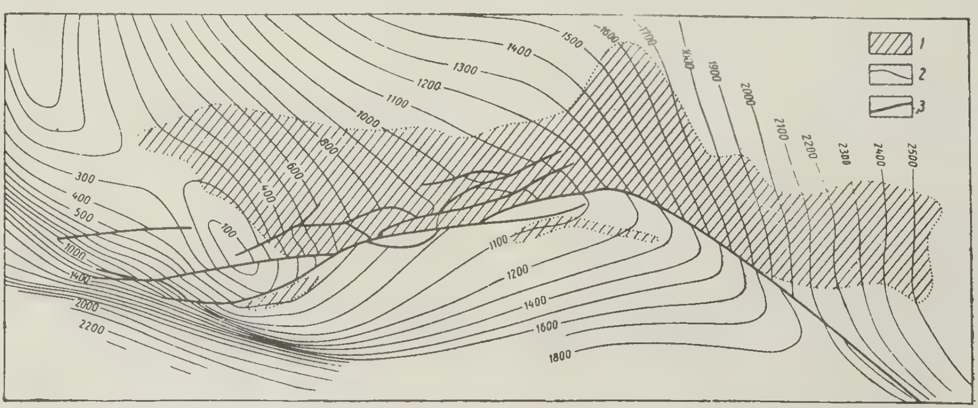


FIGURE 6. An oil trap in the Underkirmakin formation in the field of Balakhany-Sabunchi-Ramany. (1) An oil pool in the Underkirmakin formation; (2) Structural contour lines; (3) Faults.

pools. (A similar relationship was also noted by I. I. Potapov.)

The latest geological studies have established the inclined position of the largest oil pools in the eastern part of the Russian Plateau. For instance, in the Romashkino pool the altitude of the oil-water contact in different places differs up to 8 meters despite the small dip of the beds and the low position of the pool.

It is interesting to note that the inclined position of the lower boundary may also be observed in pure gas accumulations. For example, V. P. Savchenko, A. L. Kozlov, and V. N. Kortsenstein established up to 50-meter differences in the elevations of the oil-gas contact in the Severo-Stavropolsk pool, which is confined to the Paleogene sediments.

The inclined position of the bottom of the oil saturation of plateaus is indicated by somewhat different reasons than those which produce the inclination of oil pools in the region of Apsheron.

In the Devonian sediments of Bashkiria and Tataria, the pools contain light oils of low viscosity. The difference in the specific gravity of oils in the structural heights and at margins of the deposits is small because of the thinness of the oil-bearing horizon. Oxidation at the margins of the pools is not advanced far enough to hinder the change of the position of the pools under pressure of the surrounding water. At the same time, the absence of faults hinders vertical migration of light oils from their original locations.

The principal reason for the dip of oil-water contacts in the major structures in Tataria and Bashkiria is related to hydro-geological conditions in the region and to the location of Paleozoic sediments at high altitudes.

The displacement of oil pools under hydrostatic pressure is pronounced both in the form of an inclined water-oil contact and in the form of sharply rising edges of oil saturation toward the tops of beds. Similar cases can also be observed in the deposit confined to the Underkirmakin formation within the Gyurgyany field, in which the water-oil contact at the margin of the pool forms a sharply curved surface because of the pressure from the outside water (Figure 7).

Thus, identical inclinations of the water-oil contact can be related to different causes, such as to the oil oxidation at the margins of the pools prior to the tectonic deformations in geosynclinal regions, or to hydraulic factors in uplifted parts of plateaus.

The inclination of the oil-water contact may take place even during the short time of exploitation of nearby deposits.

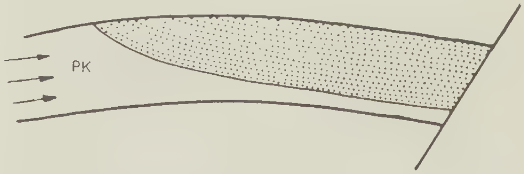


FIGURE 7. An oil trap in the Underkirmakin formation in the field of Gyurgyany.

Such a case was established by V. P. Savchenko in the region of Buguruslan. Here the oil-gas pool of Novostepanovsk had been under exploitation since 1941. The gas pressure in the highest point of the pool dropped 13 atmospheres by 1951. By the end of 1951, another gas pool was discovered 20 kilometers south of Novostepanovsk in the same group . A study of the new pool disclosed that its gas pressure had already dropped 3. 1 atmospheres and the pool itself became displaced 8 to 10 meters toward Novostepanovsk during the latter's exploitation.

B. Ya. Shornikov and I. B. Feigelson released their observations confirming the influence of the exploitation of the Sokolovogorsk pool on the Guselka pool, both confined to the V horizon of the Givetian system (Transvolga at Saratov). The pressure in the bed at the start of exploitation in Sokolovogorsk was 226 atmospheres in 1950 and 229 atmospheres in Guselka because of its position 30 meters below the former. During the exploitation in Sokolovogorsk, the pressure of the gas bed dropped from 226 to 166 atmospheres. The drop of the gas pressure in this bed affected that of the other because of their close location (the distance between the boundaries of their oil saturation is 2. 7 kilometers) and the good permeability of the gas-bearing sandstone group. Now, at the start of an experimental exploitation in the deposit of Guselka, a pressure 17. 5 atmospheres lower has been established in the V group because of exploitation of the Sokolovogorsk pool.

Reciprocal influence of oil pools was also established in the Peninsula of Apsheron. The exploitation in the Underkirmakin formation in the field of Kala (1936), accompanied by a substantial move of the surrounding waters into the former area of oil saturation, caused a drop of the original pressure in the bed of the neighboring Buzovny pool (1944).

I. I. Potapov takes the oil saturation in the structure of Balakhany into consideration when he describes the "hanging" traps. It is truly remarkable and surprising that such a deeply

eroded anticline as that of Balakhany-Sabunchi-Ramany, where the entire productive sequence from top to bottom is exposed, has been the richest oil district in the Peninsula of Apsheron. Why have oil pools remained preserved despite the fact that some horizons to which the pool are confined are exposed at the surface?

We cannot agree that the oil oxidation near the surface and the consequent sealing of the pores were the principal reasons that the pools were preserved from complete destruction. The oxidation actually took place, but most likely it was not a reason but a consequence. The principal reason was the establishment of a balance between the pressure of the surrounding water and that of the oil pool.[4] The latest exploitation gives excellent examples confirming this concept.

In a number of pools, the oil extraction and the drop in the gas pressure cause water to flow toward the pool and indicate the dependence of the low mobility of the oil, not on the location at old anticlines but on the above real reasons for preservation of oil pools in this unique oil-bearing district.

A study of oil occurrences in the structures of the Apsheron Archipelago gives a great many facts that contribute to our knowledge concerning the real reasons for the formation of the so-called "hanging" oil traps.

While oil in the Peninsula of Apsheron occurs in the PK and Kala formations generally in the form of one-sided pools, preferably confined to the eastern flanks of respective structures, in the Apsheron Archipelago we have an entirely different picture. For example, the northern anticline on the Island of Artem is oil-bearing in both the western and eastern flanks. The southern anticline on the same island has an oil pool only in the eastern flank below an overthrust, while the overthrusted and exposed western flank lost its oil because of replacement by water under pressure. Here, traces of former oil saturation occur in the form of sands penetrated by oil and preserved only on the top of the Underkirmakin layers. Further southeast, within the field of Gyurgyany, the oil pool is on the western flank, while the eastern flank is water-bearing. The structure of Neftyanye Kamni is oil-bearing on both the southwestern and northeastern flanks.

Thus a study of oil pools in the structures of the Apsheron Archipelago confirms beyond doubt both the oil saturation in both flanks of anticlines, such as in the Islands of Artem and Neftyanye Kamni, and the one-sided location of pools either in the southwestern (Gyurgyany, the bank of Darwin) or the northeastern flank (the southern anticline on the Island of Artem and the Island of Zhily) of folds. The one-sided or "hanging" position of oil pools in the region of Apsheron is principally caused by faults which enabled oil to migrate vertically and led to its loss in one of the flanks.

The formation of oil pools in the region of Apsheron was accompanied not only by vertical but also by lateral oil migration, particularly in the lower part of the productive stratum.

In connection with the oil migration and formation of pools, we have to mention an interesting article by M. A. Kapelyushnikov and T. P. Zhuze, in which the transfer of oil in a gaseous form in various deposits of the Soviet Union is discussed. Their studies established that the critical pressure in the oil-gas system at temperatures of 40 to 80 degrees centigrade varies from 250 to 500 atmospheres in certain selections of gas components and various oils. Thus oil may be in gas form and, as such, migrate in underground conditions.

Furthermore, M. A. Kapelyushnikov points out that a drop in the pressure below the critical point causes condensation of the gas phase until the balance in the oil-gas system is established under new conditions; any further drop in the pressure will cause a new disturbance of the balance and produce new portions of oil of lower specific gravity.

M. A. Kapelyushnikov attempts to base his explanation of changes in the specific gravity of oils in deposits having many oil horizons on the fact that an intermittent drop in the pressure condenses oils, the specific gravities of which drop intermittently. The studies of M. A. Kapelyushnikov, T. P. Zhuze, and others on the conditions under which oil turns into a gas phase are, according to S. I. Mironov, of great theoretical and practical interest. It is known that oil reserves can be extracted only up to 30 percent from beds of low permeability and containing certain amounts of dissolved gases. The greater part of these oils remains in capillaries with the present methods of oil exploitation. The possibility of more complete extraction of oil reserves by turning them first into a gaseous form would be a progressive and exceptionally important measure for the oil industry. M. A. Kapelyushnikov also draws a conclusion concerning oil migration and the formation of pools on the basis of his studies. There is no doubt that oil in those beds located at great depths, where pressure and temperature are high, may be in gas form and may, under certain conditions, migrate from depressions. However, we cannot agree with M. A. Kapelyushnikov that oil remains in gas form until it reaches anticlines, where accumulating beds are of minimum depth. This is true only in the case of gas-condensed oil pools.

[4] This was first noticed by M.V. Abramovich.

The conditions under which oil migrates in gas form from the deepest parts of depressions into their flanks change continuously. Therefore, oil must become condensed from hydrocarbon gases before reaching anticlines because of the drop in pressure and temperature when the gases migrate through beds located at lesser depths. The further migration along beds continues in fluid and gas form in conformity with certain concepts expressed by I. M. Gubkin. Therefore, oil may migrate along beds in gas form to a certain extent, depending on the pressure and temperature of the respective beds. It would be wrong to assume that oil pools 500 meters or deeper could be formed as a result of condensation directly within anticlines.

Let us first assume that oil in the Surakhany field was once at a greater depth, migrated in gas form from depressions and reached anticlines, and there, being partially condensed, saturated sand beds. Later, oil-bearing beds took their present positions as a result of tangential stress and still further elevation of anticlines. A substantial decrease in the depth of beds and, consequently, a decrease in pressure and temperature led to complete condensation of gases and to the formation of oil pools.

However, the study of the chemical composition of oils disproves such an assumption. If oil pools having several horizons were formed as a result of condensation within the same beds, they should have the same or very close chemical compositions, and, even more important, should not contain mineral pitch. In reality the chemical composition of oils of different groups differs sharply, and the content of mineral pitch in lower groups reaches 22 percent.

Finally, let us review the case in which lateral migration in gas form takes place only in a lower bed until reaching anticlines, and then rises along fault planes and saturates all the higher accumulating beds. In this case, oil migrating in gas form from depressions should have lost its heaviest hydrocarbons. Mineral pitch should have been adsorbed by rocks during the migration as long as the drop in pressure and temperature continued.

The presence of substantial amounts of mineral pitch in oils makes the above explanation of the origin of pools that consist of many groups unacceptable. Besides, we may express one more consideration. If pools were formed as a result of migration in gas form until it reached anticlines, we should naturally assume that lithologically controlled pools such as in the Kala layers, confined to deeper parts of structural elevations and to the pinching out of beds from which oil could not migrate any further, would consist exclusively of oils condensed in place. However, the Kala layers in the crest of the same structure of Surakhany have an oil pool.

Finally, the western part of the Peninsula of Apsheron has a unique pool, formed as a result of direct condensation: the deposit of Karadag, whose height is over 1, 200 meters. Despite the presence of condensed oil in the VII-VIIa groups, we do not find here light oils like those in the field of Surakhany. In the V group we find heavy oil with a specific gravity of 0. 920 to 0. 925.

The studies of oil-bearing regions near the coast of the Caspian, the Azov, and the Black Seas by V. V. Veber, A. I. Gorskaya, and others, and of oil fields at the Gulf of Mexico by P. Smith, proved the formation of fluid hydrocarbons, such as oil, in the present and early Quaternary marine sediments and the continued increase of their content during the decay of organic substances. These studies, according to M. F. Mirchink and A. A. Bakirov [21], confirm the correctness of the principal assumptions in the modern theory of the organic origin of oils and, as we can believe, exclude the necessity of explaining the formation of oil pools by migration of gas all the way to the locations where they form pools.

The study of the geologic composition of oil pools in the region of Apsheron disclosed numerous facts on the unconformity between the productive stratum and the underlying rocks. The peculiarities of sedimentation and tectonics in a number of structures caused the superimposition of the Kirmakin layers over the Diatomite layers, while in other structures the Underkirmakin and Kala layers overlie the Pontus formation; in places the Koun formation underlies the productive stratum.

Only the formations in the lower part of the productive stratum, particularly the KC, PK, and Kala formations, are in contact with underlying rocks. Consequently, the lateral oil migration is possible mainly in the beds of the lower part of the productive stratum directly overlying older sediments.

In the course of prospecting, many facts were gathered which indicate the great significance of the lateral migration for the formation of oil deposits in the lower part of the productive stratum.

(1) The majority of exploration drill holes recovered cores definitely with traces of oil in deep depressions far from the crests of anticlines and beyond the oil saturation in all horizons. Frequently we had an opportunity to see thick films of oxidized heavy oils on the top of drilling mud from deep holes when these crossed the Underkirmakin and Kala formations.

The assays of samples did not show oil. We must assume, therefore, that the oil found in drilling mud indicates channels of oil migration into higher horizons of the stratum.

(2) The presence of oil pools confined to areas of exceptionally favorable lithology deep in plunging flanks, not only beyond the limits of oil saturation of the horizons concerned but also far from faults, also confirms the probability of lateral migration.

(3) The presence of a deep-seated (4,250 meters), lithologically controlled deposit in the Kala formation within the field of Gousany in a syncline between the Kala, Surakhany-Kara-Chukhur and Zykh (4,850 meters) anticlines, having no faults, is also excellent evidence in favor of the tremendous significance of lateral migration.

(4) Finally, all deposits occur in the lower part of the productive stratum beyond the crests of anticlines. The decline of dip along the plunging axes of structures and the formation of terrace-shaped ledges may lead to oil accumulation far from the crests (Gyurgyany). At the same time, the upper part of the productive stratum does not carry oil in these fields. This fact also confirms the lateral migration in the lower part of the productive stratum.

Thus, all deposits in the upper part of the productive stratum were formed because of systems of faults confined usually to the central parts of anticlines which permitted vertical oil migration. The conditions of sedimentation and tectonics caused an absence of sharp disconformities between the upper and lower parts of the stratum, while its lower layers are of different ages. This fact sharply limited the possibility of lateral oil migration in the horizons of the upper part. Consequently, all of the oil occurring in the upper part found its way from the beds of the lower part of the productive stratum. We believe that the lateral oil migration in sand beds of the upper part of the stratum is not evident, but this does not exclude the possibility of the presence of still undiscovered oil pools in the same horizons, particularly in the deeper parts of structures having faults. These faults, like those known near the crest of folds, may have served as channels of vertical migration from the lower part of the stratum or as planes terminating oil deposits. We must assume that oil pools in the Balakhany layers of Peschanyi Island which are not related to independent uplifts occur because of the presence of buried mud volcanoes, similar to the one known in the field of Zykh.

We have pointed out that the lateral migration of oil was the principal factor in the formation of pools in the lower part of the stratum. The lateral migration involved the entire South Caspian depression. Oil migrated along the most permeable beds from depressions into higher points of the basin and became concentrated basically in the regions of Apsheron and Pribalkhan, in the structures of the Apsheron submarine ridge and apparently in all the folded zones around the South Caspian depression.

REFERENCES

[1] Abramovich, M. V., CHANGES IN THE PROPERTIES OF OIL IN THE RESERVOIR ROCKS IN CONNECTION WITH THE CONDITIONS OF ITS ACCUMULATION. [IZMENENYE SVOISTV NEFTI V NEFTENOSNOM PLASTE V SVYAZI S USLOVYAMI YEGO ZALEGANYA]. Work of the Geological Institute, AzFAN, t XIX, 1939.

[2] Abramovich, M. V., NEW MATERIAL ON THE GEOLOGICAL STRUCTURE OF THE LENINGRAD REGION. [NOVYE VZGLYADY NA GEOLOGICHESKOYE STROYENYE LENINSKOGO RAYONA]. Izdatelstvo Akademi Nauk Azerbaydzhanskoy SSSR, 1945.

[3] Aliyev, A. K., ON THE QUESTION OF THE OIL POOL FORMATION IN THE LOWER SECTION OF THE APSHERON PENINSULA PRODUCTIVE SEQUENCE. [K VOPROSU FORMIROVANYA NEFTYANYKH ZALEZHEI V NIZHNEM OTDELE PRODUCTIVNOY TOLSHCHI APSHERONSKOGO POLUOSTROVA]. ANKh, 1954. No. 2.

[4] Apresov, S. M., THE ROLE OF FAULT DISPLACEMENT IN OIL TRAPS. [ROL DIZYUNKTIVNOY DISLOCATSI V NEFTYANYKH MESTOROZHDENYAKH]. Aznefteizdat, 1947.

[5] Baba-Zade, B. K., THE EXPLORATION FOR NEW TYPES OF STRUCTURES IN THE EASTERN APSHERON. [V POISTAKH NOVYKH TIPOV STRUKTUR NA VOSTOCHNOM APSHERONE]. ANKh SSSR. 1948. No. 7.

[6] Bakirov, A. A., THE CONTEMPORARY STATUS, AND THE MORE IMMEDIATE PROBLEMS OF INVESTIGATING THE PROCESSES OF OIL MIGRATION IN THE EARTH'S CRUST. [SOVREMENNOYE SOSTOYANYE I BLIZHAISHCHYE ZADACHI ISSLEDOVANYA PROTSESSOV MIGRATSI NEFTI V ZEMNOY KORE]. Sovetskaya Geologya, 1956. No. 47.

[7] Brod, I. O., DEPOSITS OF OIL AND GAS. [ZALEZHI NEFTI I GAZA]. Gostoptekhizdat, 1951.

[8] Veber, V.V., Gorskaya, A.I., and M.A. Messineva. QUESTIONS ON MIGRATION MATERIALS AND THE CONDITIONS OF THEIR ACCUMULATION IN SEDIMENTS. [PROBLEMY ISKHODNOGO MATERYALA I USLOVYA YEGO NAKOPLENYA V OSADRAKH]. Sb. "Proiskhozhdenye nefti," 1955.

[9] Gorin, V.A., NORTHERN CASPIAN DEPRESSION AND THE GENESIS OF THE RESERVOIR ROCKS. [SEVERNAYA KASPIISKAYA VPADINA I GENEZIS PRODUKTIVNOY TOLSHCHI]. Doklady Akademii Nauk SSSR 1951. No. 5, t. 7.

[10] Gorin, F.A., THE CASPIAN TECTONIC DEPRESSION. [KASPIISKAYA TEKTONICHESKAYA VPADINA]. Work of the Geological Institute after I. M. Gubkina, t. XV, 1954.

[11] Gubkin, I.M., STUDIES ON OIL. [UCHENYE O NEFTI]. 1932.

[12] Gubkin, I.M., TECTONICS OF THE SOUTHERN CAUCASUS IN CONNECTION WITH THE OIL OCCURRENCE IN THIS REGION. [TEKTONIKA YUZHNOVO KAVKAZA V SVYAZI S NEFTENOSNOSTYU ETOI OBLASTI]. ONTI, 1934.

[13] Kapelyushnikov, M.A., MIGRATION AND ACCUMULATION OF SCATTERED OIL POOLS IN SEDIMENTARY ROCKS. [K VOPROSU MIGRATSI I AKKUMULATSI RASSEYANNOY NEFTI V OSADOCHNYKH PORODAKH]. Doklady Akademii Nauk SSSR, 1951. No. 8.

[14] Kapelyushnikov, M.A., Zhuze, T.P., and P.S. Ushakova., INVESTIGATIONS OF THE OIL-GAS SYSTEM UNDER HIGH PRESSURES. [ISSLEDOVANYE SISTEMY NEFT-GAZ PRI PROVYSHENNYKH DAVLENYAKH]. Proceedings of the Petroleum Institute, Akademi Nauk SSSR, 1954. t. III.

[15] Kozlov, A.L., Korsenshtein, V.N., and V.P. Savchenko. THE SIGNIFICANCE AND METHODS OF STUDYING THE HYDRAULIC PRESSURE OF UNDERGROUND WATERS. [O ZNACHENI I METODIKE IZUCHENYA NAPOROV PODZEMNYKH VOD]. N., 1954. No. 10.

[16] Melik-Pashyev, V.S., OXIDATION PROCESSES AND THE INCREASE IN SPECIFIC GRAVITY OF OIL IN THE MARGINAL ZONES OF OIL DEPOSITS. [OKISLITELNYE PROTSESSY I UVELICHENYE UDELNOGO VESA NEFTI V PRIKONTURNOY ZONE NEFTYANYKH ZALEZHEI]. NKh, 1955. No. 9.

[17] Mikhteyev, Sh. F., and A.S. Bairamov., THE "HANGING" OIL POOLS IN THE RESERVOIR ROCKS OF THE APSHERON PENINSULA. [O VISYACHIKH ZALEZHAKH NEFTI PRODUKTIVNOY TOLSHCHI APSHERONSKOGO POLUOSTROVA]. Akademiya Nauk Azerbaydzhanskoy SSR, 1949. No. 7.

[18] Mironov, S.I., SOME QUESTIONS AND PROBLEMS OF THE ORIGIN OF OIL. [NEKOTORYE VOPROSY I PROBLEMY PROISKHOZHDENYA NEFTI]. Vestnik Akademi Nauk SSSR, 1952. No. 8.

[19] Mironov, S.I., PROBLEMS OF THE ORIGIN OF OIL AND THEIR SOLUTION. [PROBLEMY PROISKHOZDENYA NEFTI I YEYE RAZRESHENYA]. Izvestiya Akademi Nauk SSSR, 1952. No. 2.

[20] Mirchink, M.F., THE CONTEMPORARY STATUS OF THE PROBLEM ON THE ORIGIN OF OIL AND BASIC PROBLEMS OF FURTHER INVESTIGATIONS. [O SOVREMENNOM SOSTOYANI PROBLEMY PROISKHOZHDENYA NEFTI I OSNOVNYE ZADACHI DALNEISHIKH ISSLEDOVANI]. Sbornik "Proiskhozhdeniye nefti," 1955.

[21] Mirchink, M.F., THE PRINCIPLES OF OIL AND GAS CLASSIFICATION. [O PRINTSEPAKH KLASSIFIKATSI ZALEZHEI NEFTI I GAZA]. IKh, 1955. No. 5.

[22] Potapov, I.I., OIL GENESIS AND THE FORMATION OF OIL POOLS WITH EMPHASIS ON THE OCCURRENCE OF "HANGING" POOLS IN THE RESERVOIR ROCKS OF THE APSHERON PENINSULA. Conference material. [NEFTEOBRAZOVANYE I FORMIROVANYE NEFTYANYKH ZALEZHEI V SVETE SUSHCHESTVOVANYA V PRODUKTIVNOY TOLSHCHE APSHERONA "VISYACHIKH" ZALEZHEI. MATERIALY DISKUSSI]. Izdatelstvo Akademi Nauk Ukrainskoy SSR, 1955.

[23] Savchenko, V.L., THE DISLOCATION OF OIL AND GAS POOLS. [SMESHCHENYE NEFTYANYKH I GAZOVYKH ZALEZHEI]. IKh, 1953. No. 1.

[24] Sarkisyan, B.M., THE DEPENDENCE OF THE QUALITY OF OIL ON THE GEOLOGICAL CONDITIONS. [ZAVISIMOST KACHESTVA NEFTI OT GEOLOGICHESKIKH USLOVI]. Aznefteizdat, 1947.

[25] Sultanov, B.I., and G.P. Tamrazyan. THE DISLOCATION OF OIL POOLS IN THE APSHERON OIL-BEARING REGION AND THEIR FORMATION. [SMESHCHENNYE NEFTYANYKH ZALEZHI APSHERONSKOY NEFTYANOSNOY OBLASTI I IKH

OBRAZOVANYE]. ANKh, 1953. No. 11.

[26] Trofimuk, A. A., THE CONDITIONS OF OIL POOL FORMATION IN THE VOLGA-URAL OIL-BEARING REGION. [USLOVYA OBRAZOVANYA NEFTYANYKH MESTOR-OZHDENI URALO-VOLZHSKOI NEFTYA-NOSNOY OBLASTI]. VI Mezhdunarodny neftyany kongress, 1956. t. I.

[27] Ushakov, A. P., THE INFLUENCE OF THE HYDRAULIC FACTOR ON THE FORMATION OF OIL POOLS. [VLIYANIYE GIDRAVLICHESKOGO FAKTORA NA FORMU ZALEZHI NEFTI]. ANKh, 1956. No. 5.

[28] Khayn, V. E., GEOTECTONIC BASES OF OIL EXPLORATION. [GEOTEKTONICHESKYE OSNOVY POISKOV NEFTI]. Aznefteizdat, 1954.

EXPERIMENTAL APPLICATION OF METALLOMETRY IN EXPLORATION FOR VEIN-DISSEMINATED (PORPHYRY) TYPE COPPER DEPOSITS IN CENTRAL KAZAKHSTAN [1]

by V. M. Volobuyev

translated by K. D. Solovieff and W. D. Romey [2]

Metallometric (geochemical) surveying should be the basic method of prospecting for copper deposits; but until recently most geologists doubted its usefulness for exploration for copper deposits, including the vein-disseminated (porphyry copper) type. They saw no reason for the extra expenditure involved in metallometry since outcrops of copper ore were easily visible. This reasoning was difficult to refute until further work with simple metallometric surveys uncovered deposits which these prospectors agreed could not have been located using ordinary geological prospecting methods. The discovery of very low-grade porphyry copper deposits may be given as an example.

Secondary sulfide enrichment zones and, in some cases, primary ore zones found in these deposits are of great economic value. Deposits with outcrops of highly oxidized ores or noticeable concentrations of secondary copper minerals either were known from prehistoric times or were discovered in recent times as a result of the initial prospecting survey (Kounrad is an example). Deposits where intensive oxidation and leaching had obscured surface traces of the deposit remained undiscovered. Pale smears of chrysocolla were found in the residuum at some ore deposits discovered by us. At others, no secondary copper minerals at all were found.

Examination of the surface relief presents a similar picture. Blocks of secondary quartzites often associated with copper deposits form rolling hills which stick up abruptly. The topography of ore outcrops in the region we studied consists of small uniform hills and takyrs, or shallow depressions. (Translator's note: Takyrs are flat, clayey areas found in Central Asian deserts. They are flooded in spring but harden in summer. They range in size up to several square kilometers.)

Porphyry copper deposits, often ill-defined on the surface, are well shown by metallometric surveys run on a scale of 1:50, 000. Copper dispersion halos cover a large area, sometimes reaching . 1-. 2 sq. km. Halos show up on one or two profile lines if a 500 x 50 meter grid is used.

These halos are characterized by very low copper concentrations in the residuum (. 04-.07%, occasionally as high as . 15%). Molybdenum, together with the copper, is present in most samples ranging from traces to . 001% and, more rarely, as high as . 005-. 01%. The lower limit of copper content which will be considered significant in exploration under conditions prevailing in the Central Kazakhstan has yet to be fixed. Originally, under more favorable geological conditions, it was taken as . 07%. Later, as some experience was acquired, it was lowered to . 04%. In certain cases, concentrations as low as . 02% should be considered.

In prospecting for porphyry copper deposits containing molybdenum, molybdenum dispersion halos should also be recorded. The latter cover wider areas than copper halos; this should be taken into account when interpreting results of the survey. Copper dispersion halos are detectable when the copper content is between . 02-. 04%. Molybdenum halos are detectable when the content is as low as . 001%.

Copper dispersion halos are found primarily in hydrothermally altered quartz porphyries, albitophyres, porphyrites, plagiogranite porphyries, granites, porphyroids, and other rocks. Secondary alteration of rocks may take the form of sericitization, kaolinization, iron-metasomatism, pyritization, and silicification. In some cases, small linear, elongated zones of intensely kaolinized, iron-metasomatized, and sericitized rocks are observed; in other cases, intensely altered zones have an irregular shape. In most cases, however, the rocks are affected by these processes more or less uniformly. Pyritization and silicification occur in a similar manner; silicification occurs along a thick network of small crevices having a definite trend. Relatively large, lenticular, quartzose masses are rarely found.

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[1] Opyt primeniya metallometrii pri poiskakh mednykh mestorozhdniy prozhilkovo-vkraplennogo tipa v tsentalnom Kazakhstane. Razvedka i Okhrana Nedr, 1957, No. 4, pp. 31-33.

[2] Minerals Research Laboratory, University of California.

After the small scale metallometric survey has turned up anomalously high copper concentrations, more detailed work is done within the dispersion halo area. A grid 50 x 10 meters is used and schematic geologic maps are made.

A 50 x 10 meter grid was selected as a result of experience showing that copper is concentrated irregularly in residual material. Halos are spotty since zones high in copper alternate with unmineralized zones. The selection of a comparatively small grid system was also influenced by the grid to be used in later surveys. For these reasons, we chose a 50 x 10 meter grid rather than the 100 x 10 or 100 x 20 meter grid normally used in detailed surveys. A magnetic survey using a 100 x 20 meter grid is conducted if basic rocks are widespread in the area chosen for the detailed survey.

Determination of the type of mineralization is the first step in a detailed survey. The area covered by residuum and the degree to which the residuum is impregnated with copper must be learned. This, in turn, makes possible a rough estimate of the size of the deposit. A cuprometric survey of the weathered bed rock is used for further details.

A cuprometric survey consists of the following steps:

(1) Small pits 1.25 square meters in cross section are dug along a grid system 50 meters x 50 meters. Along the edges of the ore-body the grid system is extended to 100 x 100 meters; in other places, a 25 x 25 meter grid may be used or trenches may be dug. Each pit is sunk 0.2-0.5 meters in the residuum of the weathered bed rock.

(2) Two "linear samples" which intersect each other are obtained from the bottom of each pit. These are processed by the usual methods as trench samples and sent to the spectroscopic laboratory. ("Linear samples" are taken from cuts 2 x1 square centimeters in cross section.) In order to check the spectrographic analysis and the quality of selection of the high-grade samples, 3-5% of the samples are sent for a chemical analysis.

(3) On the basis of the spectrographic analysis of linear samples (taking into account the results of the chemical analysis), a 1:5,000 cuprometric map is compiled. If molybdenum is present in the copper ore, a molybdenum survey map is also drawn. The arithmetic average of the analytic results for two linear samples is used to represent the concentration for each pit. Three groups are marked on the cuprometric map according to the copper content of bed rock:

Group	Copper Content
0	unmineralized
I	0.02 - 0.25%
a	0.02 - 0.10%
b	0.10 - 0.25%
II	0.25 - 0.50%

The additional breakdown of Group I is necessary to orient correctly the subsequent preliminary surveys. This is particularly necessary in case of low copper concentrations over wide areas (which may cover hundreds of thousands of square meters).

Comparison of the results of the cuprometric and metallometric surveys showed that the copper content in the weathered bed rock 0.7-1.0 meters from the surface is two or three times greater than in the residuum. The cuprometric survey determines the actual area and degree of copper concentration in the bed rock. The mineralization contours from the cuprometric survey considerably increase the dimensions shown by metallometric halos first obtained. (A threshold contour showing a copper content greater than 0.02% is used in the cuprometric survey.)

Spectrographic and chemical (control) methods of analysis for copper give similar results for small concentrations. A party of eight to ten men may require one or two months to complete the cuprometric survey of a new area, depending on the size of the deposit.

One or two holes are drilled to locate the zones of secondary sulfide enrichment and primary ore after examination of the bed rock and determination of geological structure. The results obtained give an idea of the size of the oxidized ore zones, secondary sulfide enrichment zones, and the content of copper.

Evaluation of deposits is done on the basis of the above-mentioned work. In predicting reserves according to category C_2 (sic), contouring accuracy in the ore-bearing area using cuprometric surveying, size of the zone of secondary sulfide enrichment and average copper content must be accurately determined.

Contouring accuracy in the survey is defined as the degree of certainty that economic ores occur in depth under the area within the contour. The contouring accuracy for leached materials where the copper content in porphyry copper primary ore is 0.1-0.25% (Group Ib) is 40%, according to G. G. Gudalin and F. I. Kovalev [1]. In the second group where the copper content is 0.25-0.50%, accuracy is 86.7%. In determining the accuracy of contouring, bore-

holes showing chalcocite ores, as well as those showing economic primary ores, were taken into consideration.

A comparison between spectrographic analytic results and drilling results in the cuprometric survey was not made because of a lack of sufficient boreholes.

A reliable determination of the area to be used in calculating reserves may be made on the basis of Gudalin and Kovalev's experimental data[1]. For the areas having Group I ores, we suggest a coefficient of .4 and for the areas of Group II ores .367.

The size of the secondary enrichment zone and the average copper content necessary for calculation of reserves are determined on the basis of drilling results. In checking the calculations (to see if they are realistic) the results of exploratory work on similar deposits in the area should be used as a guide.

In conducting a metallometric survey under normal field conditions, it takes a party three or four months to complete a detailed survey of a deposit and evaluate it. Most of the time is taken by the drilling, digging trenches, and collecting and processing of samples in the laboratory.

REFERENCES

[1] Gudalin, G. G., and F. I. Kovalev. Copper (Med.) Series: "EVALUATION OF ORE DEPOSITS DURING PROSPECTING AND EXPLORATION", Issue No. 6, 1951.

[2] Smirnov, S. S., THE OXIDATION ZONE OF SULFIDE DEPOSITS. [ZONA OKISLENIYA SULFIDNYKH MESTOROZHDENIY]. Acad. of Sci., USSR, 1951.

THE OUTLINES OF STRATIGRAPHY OF PRECAMBRIAN ROCKS IN THE DZHAGDA AND TUKURINGER MOUNTAIN RANGES[1]

by N. A. Bogdanov

translated by Dr. Salih Faizi

The Precambrian formations cropping out along the Tukuringer and Dzhagda Ranges [Editor's note - The Dzhagda and Tukuringer Mountains form a continuous chain roughly parallel to the Siberian-Manchurian border, between 50 and 55 degrees North and 120 and 135 degrees East.] have remained inadequately studied until recently. The intensively deformed and metamorphosed strata of these regions were first described late in the last century by P. B. Rippas, V. N. Zverev, and E. E. Anert. Later, A. N. Churakov (10), in his monograph on Precambrian formations of the Far East and the eastern Transbaikal region (based upon the data obtained in the 1930's by the expeditions of the Academy of Sciences of the USSR), divided the old metamorphic formations occurring along the Tukuringer and Dzhagda Mountains into:

(a) Archean, composed of various gneisses and amphibolites.

(b) Proterozoic, consisting of a uniform sequence of quartz-muscovite, actinolite, chlorite, and other schists with enclosed marble and quartzite beds.

M. S. Nagibina [6] described the metamorphic rock of the inter-river area between the Zee and Selemya Rivers in detail as unconformably overlying the Archean gneisses and schists. With respect to the composition, these metamorphic rocks are very similar to those shales which crop out along the Tukuringer Range. The metamorphic rocks of the inter-river area are united by her under the name Tukuringer formation of Proterozoic-Lower Paleozoic age. Three years of my investigations in the basin of the middle Zee River from the Great Tynda River in the west to the valley of the Dep River in the east, the investigations of 1955 to 1956 carried out by geologists of the Far Eastern Geological Administration, and the geological mapping of these regions carried out by VSEGEI (All Union Scientific-Research Geological Institute) permits us to divide the complex of schists cropping out along the Dzhagda and Tukuringer Ranges into series, groups, and formations. Particularly within the sequence of schists occupying a large uplift of latitudinal strike and overlying with sharp angular unconformity the gneisses of the Ust-Gilui Series, I distinguish two series: those of Dzhagda and Unya-Boma,[2] trending for long distances and sharply differing from each other with respect to both the mineral composition and the grade of metamorphism (see the table).

Ust-Gilui Series

The oldest metamorphic rocks cropping out along the Dzhagda and Tukuringer Ranges are, according to A. N. Churakov [10] and M. S. Nagibina [6], those of the Ust-Gilui series, composed of various gneisses interbedded with schists, to a lesser extent with marbles and amphibolites, and intruded by granite-gneisses. The rock of the Ust-Gilui series occupy broad areas in the northern slopes of the Tukuringer and Dzhagda Ranges and the point of Gonya. Schists and gneisses of similar composition are, according to D. S. Korzhinsky [2], broadly distributed on the southern slope of the Stanovoi Range. A thick sequence at the base of the series consists of biotite and biotite-hornblende interbedded with thin layers (up to a few tens of meters thick) of muscovite, muscovite-biotite, and garnet gneisses. In the next highest group, thin layers of marbles and amphibolites are enclosed in gneisses. The amphibolites have varieties containing large crystals of pink garnet. The visible thickness of the UST-Gilui series reaches several kilometers. The gneisses of the Ust-Gilui series are intensively metamorphosed sedimentary rocks. This is indicated by the presence of marble lenses and layers of garnet and muscovite schists which are rich in alumina minerals, garnet, muscovite, biotite, and others. The majority of rocks are of banded texture. The original composition of the rocks of the Ust-Gilui series was apparently close to that of terrigenous sediments containing interbedded limestones.

The above metamorphic rocks are intruded by biotite and biotite-hornblende granite-gneisses, which in places occur in the form of magmatic injections in biotite paragneisses and are accompanied by migmatites. Dikes accompanying granite-gneiss intrusives are composed of aplites and pegmatites.

The composition of the gneiss of the Ust-Gilui series is very close to that of the Archean

[1] Skhema stratigrafii dokembriyskikh otlozheniy khrebetov Dzhagdy i Tukuringra. Sovyetskaya Geologiya, No. 4, 1958.

[2] The Unya-Boma series are first distinguished by P.B. Rippas.

The Division of the Precambrian Formations in the Dzhagda and Tukuringer Ranges
(from bottom to top)

Ages	Series	Thickness in meters	Composition of Rocks	Magmatism
Upper Proterozoic	Unya-Boma	5000 to 6000	Sandstones, sandy shales, phyllites, quartz-porphyry, orthophyre, and limestone	
			Unconformity	
Lower and Middle Proterozoic	Dzhagda	2500 to 3000	Dzhugdagin formation: schists of epidote, epidote-actinolite, quartz-graphite-muscovite, quartzites, schistose basic effusives and limestones	
		3000 to 4300	Algai formation: schists of quartz-mica, graphite-quartz-mica, epidote-actinolite, and quartzites	
		500 to 800	Chala formation: quartzite-like sandstones, schists of quartz-amphibole, amphibole and chlorite	
			Unconformity	
Upper Archean	Ust-Gilui	Several thousands	Gneisses with biotite, biotite-hornblende, garnet, amphibolites, muscovite-biotite schists and marbles	Intrusion of granite-gneisses accompanied by migmatization

gneisses described by M. S. Nagibina [7] along the Amur River, up river from the town of Blagoveshchensk. Gneisses of similar composition were described by D. S. Korzhinsky[2] along the mountain range of Stanovoy and by V. A. Obruchev [8] and other geologists in the mountains of the middle Vitim and in western Transbaikal, where they consist of biotite, garnet, muscovite-biotite, and other gneisses and amphibolites of Archean age.

Among metamorphic rocks which are comparable with those of the Ust-Gilui series and occurring in farther eastern regions, we may mention biotite and biotite-hornblende gneisses of Upper Archean age described in detail by V. V. Onikhimovsky [9]. Upon the basis of these similarities, we, as do other geologists who have worked along the Tukuringer and Dzhagda Ranges, believe the gneisses of the Ust-Gilui series to be of Upper Archean age.

It must be noted that gneisses exposed along the Tukuringer and Dzhagda Ranges as a whole differ from the Archean complex of gneisses described by Yu. K. Dzevanovsky and E. M. Lazko [1] within the shield of Aldan. The Ust-Gilui series apparently belong to extreme upper parts of the Archean section, to a part which does not occur in the shield of Aldan.

Dzhagda Series

The rocks of the Ust-Gilui series are unconformably and transgressively overlain by those of the Dzhagda series, which compose the central and southern parts of the Tukuringer Range and occupy a broader area due east toward the Dzhagda Range, where they form the principal rock sequence. The rocks of this series were described by M. S. Nagibina [6, 7] in various districts of the upper Amur Basin, where they also unconformably overlie Archean rocks exposed in the core of anticlines.

In the upper Amur Basin, along the Tukuringer Range and in the western part of the Dzhagda Range, and Dzhagda series of metamorphic rocks may be subdivided, on the basis of detailed studies, into three group of differing compositions.

The lower part of the Dzhagda series consists of the Chala formation, the most complete section of which the author observed in the basin of the Chala River (east tributary of the Urkan River). Here the gneisses of the Ust-Gilui series are overlain with sharp angular unconformity (the strikes of the two series differ by 20 to 30 degrees) and stratigraphic interruption by metamorphic quartzite-like sandstones with quartz-mica and quartz-epidote cement and interbedded with amphibolites and chlorite schists. The sandstones are overlain by amphibole schists. The visible thickness of the Chala formation reaches 500 to 800 meters.

The Chala formation pass into quartz-mica schists of the Algai formation. Unfortunately, we did not see the direct contact between these two formations. However, according to V. V. Onikhimovsky and a number of other geologists who studied the eastern part of the Dzhagda Range, the amphibole schists and quartzite-like sandstones directly overlying the Archean gneisses similar to the gneisses of the Ust-Gilui series, are in turn conformably overlain by quartz-mica schists, which, according to our classification, comprise the Algai formation. The base of the Algai formation in the section along the Algai River (left tributary of the Zee River) is composed of thinly laminated quartz-mica-actinolite and quartz-mica schists interbedded with thin beds of dark green actinolite-chlorite and graphite-mica-quartz schists containing small inclusions of pyrite. The next higher group of the section consists of quartz-mica schists, which in turn pass into black graphite-mica-quartz schists with enclosed beds of thinly laminated quartzites and green epidote-actinolite schists. The total thickness of the Algai formation reaches 3, 000 to 4, 300 meters.

The schists of the Algai formation cropping out along the middle Zee River, 6 kilometers south of the mouth of the Gilui River, pass in complete conformity through a transitional zone into the Dzhugdagin formation, the most complete section of which we studied in the basin of the Bolshoy Dzhugdagin River (right tributary of the Dep River).

The lower part of the Dzhugdagin formation consists of epidote and epidote-actinolite schists interbedded with thin layers of metamorphosed basic effusives, actinolite and quartz-muscovite schists. Higher in the section, epidote schists pass into gray and silver-gray quartz-muscovite and quartz-graphite-muscovite schists with enclosed quartzite beds of yellow or banded colors. In the upper part of the section we found several enclosed beds of white marbleized limestones and red-colored jasper-like quartzites 50 to 70 meters thick. The total thickness of the Dzhugdagin layers reaches 2, 500 to 3, 000 meters, while the total thickness of the Dzhagda series reaches 6, 500 to 7, 000 meters

The Unya-Boma Series

The Dzhagda series are overlain by the Unya-Boma series with an angular unconformity and stratigraphic interruption. The direct contact of the two series we observed along the upper reaches of the Algai River in the Tukuringer Range. Here the metamorphosed fine-pebbled conglomerates and coarse-grained sandstones of the Unya-Boma series overlie with angular unconformity various rocks of the Algai and Dzhugdagin layers. The lower part of the Unya-Boma series consists of a thick sequence (up to 600 meters) of coarse-grained dark gray metamorphosed sandstones with enclosed beds of metamorphosed interformational conglomerates and sandy schists. Higher in the section the sandstones gradually pass into sandy schists with a coal-quartz-muscovite cement, interbedded with thin layers of metamorphosed sandy schists and schistose acidic effusives (quartz porphyry and orthophyre). The sandy schists are overlain by a uniform sequence of phyllites, which only rarely contain enclosed beds or lenses of metamorphosed limestones and schistose acidic effusives.

The thickness of the Unya-Boma series sharply increases from west to east. While its thickness along the Zee River does not exceed 2, 000 to 2, 500 meters, it reaches 5, 000 to 6, 000 meters in the upper reaches of the Unya and Boma Rivers, according to P. N. Ponomarev.

As we can see from the description of the Dzhagda and Unya-Boma series, the metamorphism of their rocks is somewhat different. The Dzhagda series are more intensively metamorphosed as a result of regional metamorphism that turned the thinly laminated terrigenous sediments into rocks composed chiefly of new minerals such as biotite, muscovite, actinolite, graphite, and others. The thin blankets of the acidic effusives became also intensively metamorphosed and now occur interbedded with metamorphic rocks of sedimentary origin. This series is folded into nearly east-west striking isoclinal folds on the flanks, complicated by smaller folds and scale-shaped faults.

The rocks of the Unya-Boma series are metamorphosed to a lesser extent. The newly formed minerals in them consist of muscovite, sericite, and chlorite, rarely epidote and actinolite. The original structures of the rocks are recognizable in the majority of cases, and this permits us to recognize the original rocks easily. The Unya-Boma series form symmetrical folds striking east-westerly and dip 20 to 40 degrees in both flanks. The folds composed of this series of rocks strike at a sharp angle to those of the Dzhagda series. Metamorphic complexes of both the Dzhagda and Unya-Boma series are cut by numerous faults having various displacements, in the zones of which the metamorphism of the rocks is more intensively pronounced in both series.

The Age of the Metamorphic Formations of the Dzhagda and Unya-Boma Series

The age determination of the rocks comprising the Dzhagda and Unya-Boma series overlying the upper Archean gneisses of the Ust-Gilui series is a very difficult problem.

In the east, in the Amgun Valley, N. P. Savrasov found algae, a typically Proterozoic Conophyton, in phyllites which lithologically are completely similar to those of the Unya-Boma series.

In the eastern part of the Dzhagda Range, the Dzhagda and Unya-Boma series are overlain by Devonian rocks. In the inter-river area between the Nora and Mamyn Rivers, F. A. Makarenko [5] found rocks with Silurian fauna, which unconformably overlie the schists of a metamorphic sequence. The base of the Silurian section is, according to him, composed of conglomerates with pebbles of phyllites and quartz-mica schists. The relation of the metamorphic sequence to the Cambrian rocks described by L. I. Krasnyi, northeast of the Dzhagda Range, is still not clear.

The metamorphic rocks of the Dzhagda and Tukuringer Ranges are comparable to those occupying the regions of Khingan-Bureinsk and Kur-Urma described by P. N. Kropotkin, K. A. Shakhovorstova, S. A. Salun [4], and V. V. Onikhimovsky [9]. These authors believe a sequence of quartz-muscovite, quartz-graphite-muscovite, and other schists, containing lenses and thin beds of marbles and greenstones to be of Lower and Middle Proterozoic Age and hold that at the same time these rocks are very similar to ours, with respect to both their composition and grade of metamorphism. The Unya-Boma series can also be compared with the Niman and Igincha formations of Upper Protorozoic age composed of phyllites and schistose sandstones with enclosed beds of limestones.

The absence of dolomites corresponding to those known in the Murandav formation of the Malyi Khingan River may be explained by the difference in the upper Proterozoic sedimentation in these regions.

On the basis of the data gathered by F. A. Makarenko, P. N. Kropotkin, and V. V. Onikhimovsky, we believe the Dzhagda series to be of Lower and Middle Proterozoic and the Unya-Boma series to be Upper Proterozoic Age.

It is also very possible that the upper part of the Unya-Boma series, consisting of phyllites and limestones and containing algae, is identical with the Sinian System broadly distributed in the northeastern part of the Chinese Shield.

We must note that lithologically the thick Proterozoic sequence of the Tukuringer and Dzhagda Ranges differs sharply from the Proterozoic rocks known in the eastern part of the Aldan Shield which is composed of weakly metamorphosed sandstones and limestones [1].

Thus, we may at this time assume that as early as the Proterozoic era the present territory of the Tukuringer and Dzhagda Ranges and the Upper Amur Basin were areas where sedimentation of tremendously thick layers in geosynclines took place. These beds consisted of terrigenous rocks alternated by blankets of basic and acidic effusives and horizons of limestones and dolomites. The pattern of distribution of the above types of rocks cannot be discussed at the present stage of knowledge about them, but we may point out that the most intensive Proterozoic vulcanism took place in the regions between the Zee and Selemya Rivers[6].

The Precambrian formations in the Dzhagda and Tukuringer Ranges comprise a complex of metamorphic rocks in which both Archean and Proterozoic rocks are present. The Proterozoic section in these regions apparently is one of the most complete Precambrian sections in the southern part of the Soviet Far East and undoubtedly deserves further and more detailed study.

REFERENCES

[1] Dzevanovsky, Yu. K., and E. M. Lazko. STRATIGRAPHY OF THE ARCHEAN OF THE ALDAN SHIELD. [STRATIGRAFYA ARKHEYA ALDANSKOGO SHCHITA]. Geol. sb. Lvovsk. geol. o-va pri inte. 1956, No. 2-3, 80-94.

[2] Korzhinsky, D. S., CROSS-SECTION OF THE STANOVOY RANGE ALONG THE AMUR-YAKUTSKOY MAIN LINE, AND ITS GEOLOGICAL COMPLEXES. [PERESECHENYE STANOVOGO KHREBTA PO AMURO-YAKUTSKOY MAGISTRALI I YEGO "GEOLOGICHESKYE KOMPLEKSY."] Tr. TsNIGRI, vyp. 41, 1935.

[3] Krasny, L. I., Chemekov, Yu. F., and E. E. Bulvanker. THE FIRST DISCOVERY OF THE CAMBRIAN IN THE DZHAGDA (KHABAROVSKY AREA). [PERVYE NAKHODKI KEMBRIYA V KHREBTE DZHAGDY (KHABAROVSKY KRAY)]. Dok. AN SSSR, 1954, t. 96, No. 4.

[4] Kropotkin, P. N., Shakhvorsrova, K. A., and S. A. Salun. THE TECTONICS AND SOME QUESTIONS OF METALOGENESIS OF THE SOUTHERN PART OF THE SOVIET FAR EAST. [TEKTONIKA I NEKOTORYE VOPROSY MATALLOGENII YUZHNOY CHASTI SOVETSKOGO DALNOGO VOSTOKA]. Mat. po geologii magmatizmu i ryd. mest. D. V. Zabaykalya, t. II, M., Geol. in-t AN SSSR, 1953.

[5] Makarenko, F. A., NEW DATA ON THE STRATIGRAPHY AND DISTRIBUTION OF THE SILURIAN IN THE FAR EAST (ZEYSKO-SELEMDZHINSKY INTER-RIVER AREA). [NOVYE DANNYE PO STRATIGRAFII I RASPROSTRANENYU SILURA NA DALNOM VOSTOKE (ZEYSKO-SELEMDZHINSKOGO MEZHDURECHYA)]. V sb. "Akademiku V. S. Obruchevu k pyatidesyatiletyu nauchnoy i pedagogicheskoy deyatelnosti," t. 1, izd. AN SSSR, 1939.

[6] Nagibina, M. S., MATERIALS ON THE STRATIGRAPHY OF THE PALEOZOIC IN THE ZEYE-SELEMDZHINSKY INTER-RIVER AREA. [MATERIALY PO STRATIGRAFII PALEOZOYA ZEYE SELEMDZHINSKOGO MEZHDURECHYA]. Sb. "Voprosy geologii Azii." T. 1, M., Izd. AN SSSR, 1954.

[7] Nagibina, M. S., THE GEOLOGICAL STRUCTURE OF THE LEFT BANK OF THE AMUR RIVER FROM N. KUZNETSOVO TO BLAGOVESHCHENSKA MT. [GEOLOGICHESKOYE STROYENYE LEVOBEREZHYA R. AMURA OT S. KUZNETSOVO DO G. BLAGOVESHCHENSKA]. Tr. IGEMa AN SSSR, vyp. 3, 1956.

[8] Obruchev, V. S., PRECAMBRIAN OF THE BAIKAL HIGHLANDS AND THE MIDDLE VITIMSKA MOUNTAIN COUNTRY. [DOKEMBRY BAYKALSKOGO NAGORYA I SREDNE-VITIMSKOY GORNOY STRANY]. Stratigrafya SSSR, t. 1, Dokembriy, M.-L., izd. AN SSSR, 1939.

[9] Onikhimovsky, V. V., STRATIGRAPHY OF THE PRECAMBRIAN AND CAMBRIAN IN THE KHINGANO-BUREIA AND KUR-URMYSKY REGIONS. [STRATIGRAFYA DOKEMBRYA I KEMBRYA KHINGANO-BUREINSKOGO I KUR-URMYSKOGO RAYONA]. Soveshchanye po razrab. univ. stratigr. skhem D. V. (tezisy dokl. i vystup.). Khabarovsk, 1956.

[10] Churakov, A. N., THE PRECAMBRIAN OF THE FAR EAST AND WESTERN TRANS-BAIKAL REGION. [DOKEMBRY DALNEGO VOSTOKA I VOSTOCHNOGO ZABAYKALIYA]. Stratigrafya SSSR, t. 1, M.-L., Izd. AN SSSR, 1939.

[11] Yarmoluk, V. A., THE PROTEROZOIC OF THE ALDAN MASSIF. [PROTEROZOY ALDANSKOY PLITY]. Sb. materialov po geologii i polezn. iskop. Dalnogo Vostoka. M., Gosgeolizdat, 1956.

HERCYNIAN STRUCTURAL-FACIES ZONES of the EASTERN BALKHASH REGION[1]

by P. A. Rengarten

translated by L. Drashevska

The Eastern Balkhash region includes the territory of Eastern Kazakhstan situated east of the 78th meridian and including a considerable part of the Western Tarbagatay Range in the northeast, the watershed between the rivers Bakanas and Tokrau in the northwest, the hilly plain of the eastern part of the Balkash-Alakul depression, and a small section of the northern foothills of the Dzhungarian Alatau in the south.

Some geologists studying eastern Kazakhstan are of the opinion that during the Middle and Late Paleozoic a single Dzhungaro-Balkhash Intrageosyncline existed; its northern boundary was formed by the Tarbagatay Salair uplift, and the southern boundary - by the Khantaus system of Salairian folds (2, 3, 4 and others).

As a matter of fact, if a few geologic columns of separate, well-studied sections of south Dzhungaria and Northern Balkhash region are juxtaposed, then a considerable similarity is noticed; it seems that this similarity is evidence of a common process of accumulation of sediments, a common history of geologic development, and, consequently, evidence of the existence of a single Dzhungarian-Balkhash Intrageosyncline.

However, the results of geological and aerial magnetic surveys performed in the Eastern Balkhash region by geologists of the All-Union Aerial Geological Trust, V. V. Galitsky, S. N. Golyshev, V. E. Gendler, N. M. Yefremova, G. G. Marchenko, E. I. Olli, V. P. Ponikarov, B. Ya. Ponomarev, A. A. Rozenkrantz, M. B. Staal and B. Z. Uretsky, under the supervision of the author, gave a basis for a more accurate interpretation of the geology of this interesting region. On the basis of voluminous factual material three zones have been distinguished in this region greatly differing in regard to their geologic development during the Hercynian. The zones are as follows:

(1) Northern, or Tarbagatay;
(2) Central, or Bakanass;
(3) Southern, or Balkhash.

Boundaries between the zones go along great regional, probably, deep-seated fractures.

The Tarbagatay and Balkhash zones are characterized by a predominance of Devonian and Lower Carboniferous sedimentary rocks, whereas the Bakanass zone is an area of extensive distribution of volcanogenic rocks of the Middle and Late Devonian, Carboniferous, and Permian periods. Rocks from different geologic zones were positively correlated on the basis of large collections of fauna and flora defined by N. V. Litvinovich, M. S. Potapova, L. I. Kaplun, O. N. Nasikanova, A. N. Krishtofovich, and M. I. Borsuk.

However, differences between above geologic zones are not limited by facies peculiarities of synchronous deposits and are not local or random. It will be shown subsequently that each zone is characterized by specific conditions of the accumulation of deposits, by certain values of thicknesses of sediments, by the manifestations of magmatism and metallogeny, i. e., by the whole tendency of geologic development exhibited during the Hercynian stage. Each of the zones is characterized by a particular type of magnetic field, as a synthesis of all the above mentioned characteristics. The foregoing remarks are considered evidence that differences between the zones are of particular character and subject to certain regularities (Figure 1).

The northeastern part of the region is occupied by the Western Tarbagatay Range presenting a large asymmetrical anticlinorium of complicated structure, stretching in the northwestern direction. The southwester flank of the anticlinorium, steep and short, is truncated by the regional Ayaguz-Urdzharian fracture. The region's oldest rocks are seen in exposures adjoining this fracture. These are Ordovician sandstones and conglomerates forming the anticlinorium's core. In the northern flank of the anticlinorium are found Ordovician and Lower Silurian basic effusives, jaspers, limestones, and sandstones, and also rocks inferred to be Upper Silurian: sandstones and siltstones with rare occurrences of intermediate and acid effusives.

The presence of Lower Devonian deposits in the Tarbagatay Range has not been proved. Volcanogenic deposits of the Eifelian stage are localized within a narrow belt stretching in the northwestern direction on the northern slope of the range. Higher in the geologic column, deposits of the Givetian stage (Upper Devonian and lower part of the Lower Carboni-

[1] Gertsinskye strukturno-fatsialnye zony vostochnogo Pribalkhashya. Sovetskaya Geologya, 1958. No. 4, pp. 3-17.

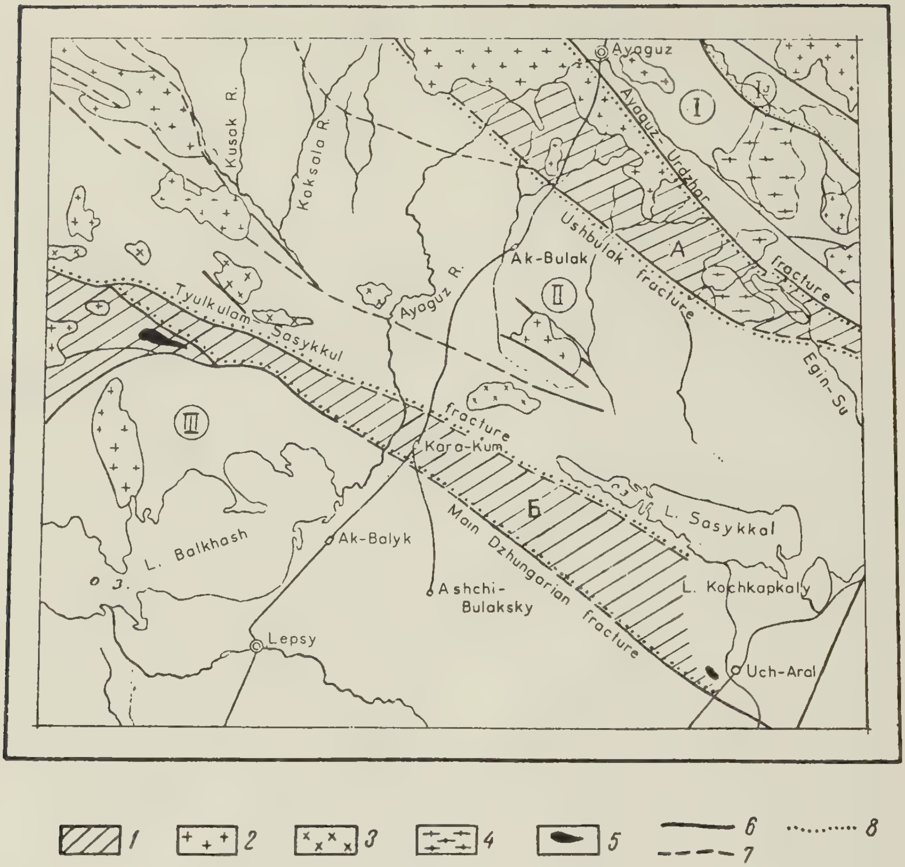

FIGURE 1. Structural-facies zones of the Eastern Balkhash region.

I - Tarbagatay Intrageanticline; Ia - the internal trough in the Tarbagatay geanticline; II - Bakanass Intrageosyncline; III - Balkhash Intrageanticline.

1 - mobile elements of the earth's crust - zones of deep seated fractures: A - Southern Tarbagatay zone; B - Northern Dzhungarian zone; 2 - Permian granites; 3 - Upper Carboniferous granodiorites; 4 - Hercynian granitoids undivided; 5 - Ultrabasic intrusions; 6- Deformations involving fractures, established by geologic observations; 7 - Deformations involving fractures, assumed, as well as established by aerial magnetic survey; 8 - boundaries of shifting of structural-facies zones.

ferous) are found, mostly represented by sedimentary rocks. Younger pre-Tertiary rocks are absent in the Tarbagatay, with the exception of volcanogenic deposits, evidently belonging to the Namurian or Middle Carboniferous sediments and developed in some places on the northern slope of the range.

South of the Western Tarbagatay Range, is located the eastern part of the spacious Balkhash-Alakul depression, or properly Alakul depression. This is a graben-synclinorium and in geologic profile two sections of rocks are clearly distinguished: Paleozoic sediments, represented mostly by volcanogenic, intensively contorted rocks of the Upper Devonian, Carboniferous, and Lower Permian, and unconsolidated Tertiary and Quaternary deposits. Mesozoic sediments are not definitely reported here.

The thickness of unconsolidated Cenozoic sediments attains 1000 m. in the southern part of the Alakul depression. Westwards the thickness of the Cenozoic cover decreases and is not more than a few dozen meters near the eastern coast of Lake Balkhash. The Alakul depression is adjacent to the Tarbagatay anticlinorium along the regional Ayaguz-Urdzhur fracture.

South of the Alakul depression, the intensive mountainous structure of the Dzhungarian Alatau rises, presenting a complicated system of folded and fold-fault structures. Only the northern margin of the Dzhungarian Alatau lies in the region under discussion. For the most

part, sedimentary rocks of the Devonian and Carboniferous periods are found in this area.

In the western section of the region, on the northern and eastern coasts of the Lake Balkhash, homogeneous terrigenous deposits are exposed, represented by sandstones and tuffaceous sandstones of all the series of the Devonian system and of the Lower Carboniferous. Among these deposits, in the tectonic block, jaspers and metamorphosed basic effusives, tuffs, and siliceous rocks are found, presumably Lower Silurian or older.[2] These rocks are associated areally with hyperbasic formations.

Near the Tyulkulam Mountains, an anticlinal fold is found; along its axis, the large Tyulkulam-Sasykkul fracture stretches. In the core of the fold are exposed Lower Devonian deposits which, according to the data of V. V. Galitsky and S. N. Golyshev, are represented by thick (up to 2600 m.) homogeneous beds of very fine- and fine-grained gray and greenish-gray sandstones with rare strata of black coaly shales. All these beds are quite homogeneous; no facies changes are observed.

Deposits of the Lower Devonian are overlain with conformity by deposits of the Middle Devonian which are well-developed on the flanks of the above-mentioned anticline. Here the facies differences are clearly seen in deposits of the northern and southern flanks of the anticline. The southern flank is characterized by shales, sandstones, and some calcareous sandstones and limestones, while mostly sandstones, tuffaceous sandstones and effusives (latter in the uppermost part of the geologic column) are exposed in the northern flank. The thickness of the Middle Devonian sediments increases rapidly from 1400 m. in the southern flank to 2500 m. in the northern flank of the anticline.

Thus it is clearly seen that a considerable downwarping of the territory situated northeast of the Tyulkulam-Sasykkul fracture started in the later half of the Middle Devonian, probably at the beginning of the Givetian age. An abrupt change in the thickness of sediments from 1400 to 2500 m. along a distance of less than 10 km. could hardly be explained by a simple downwarping without deformations involving faulting with intensive vertical movements along the above-mentioned fracture which formed a well-marked boundary.

A still greater change in facies and thicknesses of sediments of the investigated region is observed in the Upper Devonian. According to data of V. V. Galitsky and S. N. Golyshev, a normal sedimentary facies of sandstones, calcareous sandstones and limestones is developed in the southern part of the region. In the north, the synchronous Upper Devonian deposits are represented almost exclusively by volcanogenic rocks with predomination of porphyrites and porphyritic tuffs. The thickness of deposits increases from south to the north, from 700 to 2800 m. In the area of the distribution of sedimentary facies, i. e., in the territory situated southwest of the Tyulkulam-Sasykkul fracture, the thickness of deposits increases from 700 m. in the south to 1100 m. in the north. Hence, the continuous intensive downwarping, associated with movements along the Tyulkulam-Sasykkul fracture extended over areas adjacent to the south, which were also downwarped, but to a smaller degree and probably without deformations involving fracturing.

The process of separation of two different structural areas continued in the Lower Carboniferous. Within the Balkhash zone, which was relatively quiet, Paleozoic sediments younger than Tournaisian are not known, and, beginning with the second half of the Lower Carboniferous, this zone entered a new stage of gradual consolidation under conditions of the continental regime. Simultaneously, the territory bordering the north Bakanass zone of intensive downwarping continued to undergo an uneven sinking and was filled up with thick masses of Carboniferous and Permian volcanogenic deposits.

Quite analogous developments took place in the northeast of the Eastern Balkhash region, where distinct facies and thickness changes are observed along the Ushbulak fracture.

Lower Devonian deposits are absent within the Tarbagatay zone. In the upper half of the Middle Devonian (the Givetian stage) a distinct facies change occurs along the Ushbulak fracture: mottled conglomerates and red sandstones extend northeast from the fracture, quartz and diabasic porphyrites and porphyritic tuffs (the upper part of the geologic column) are exposed southwest of the fractures. Considerable changes in the thicknesses of rocks were not recorded here, probably because the full thickness of volcanogenic masses is not exposed here.

The Frasnian and Famennian series can be distinguished in the Upper Devonian deposits of this zone. After the data of V. P. Ponikarov and A. A. Rozenkrants, the Frasnian series are represented north of the Ushbulak fracture predominantly by siltstones with strata of fine-grained sandstones and conglomerates composed of small pebbles. Limestone lenses of small thickness occur more seldom. The thickness of the Frasnian series is about 900 m. Southwest of the Ushbulak fracture only the upper part of the Frasnian series is exposed.

[2] Evidently these are analogues of the Urtyndzhalsk series of Central Kazakhstan which is inferred now to belong to the Riphaeus group (Ed.).

It is represented almost exclusively by volcanogenic rocks: tuffaceous agglomerates and conglomerates, banded tuffs, plagioclase and pyroxene porphyrites; tuffaceous sandstones occur more seldom. Limestone lenses with fauna occur in the upper portion of the geologic column. The total thickness of the exposed rocks attains 750 m.

Northeast of the Ushbulak fracture Famennian sediments are represented by conglomerates and sandstones, often calcareous, whose thickness is not more than 100 m. Southwest from the fracture, the Famennian stage is represented by volcanogenic deposits, mostly by amygdaloidal porphyrites in the basal part of the section, and by various tuffs, tuffaceous conglomerates and sandstones with strata of porphyrites and quartz porphyrites in the upper part of the section. The total thickness of deposits of the volcanogenic facies of the Famennian stage attains 1500 m.

According to the data of V. P. Ponikarov and A. A. Rozenkrants, Lower Carboniferous deposits (Tournaisian stage) near the zone of the Uzhbulak fracture are represented in the northeast by limestones, sandstones, and siliceous shales having a total thickness up to 450 m. In the southwest, Tournaisian sediments include shales, sandstones, limestones and basic effusives - diabasic porphyrys and tuffs - with a total thickness up to 750 m.

Paleozoic sediments younger than those of the Tournaisian stage (probably, younger than the Lower Visean) are not found within the Tarbagatay zone. It can be considered that the beginning of the Early Visean Age in the Balkhash and Tarbagatay zones was marked by the beginning of the stage of the platform development and a gradual consolidation of the area.

The situation was completely different at that time in the Bakanass zone. Here deposits of the lower half of the Lower Carboniferous Series (Tournaisian-Lower Visean) are overlain by a marked disconformity also of Visean-Namurian volcanogenic deposits, which, according to A. A. Rozenkrants, are represented by two sections.

1. The lower section consists of diabasic, and to a smaller degree of andesitic porphyries, and quartz albitophyres - in the lower part of the geologic column; it consists of alternating andesitic and amygdaloidal, diabasic, and dacitic porphyrites, agglomeratic lavas of albitophyres, and, more seldom, of paleobasalts, tuffs, and tuffaceous breccias - in the upper part of the column. At the very top of the section a thin interstratification of porphyritic tuffs with porphyries and albitophyres is observed. The total thickness is around 1000 m.

2. The upper section is very characteristic and is composed of riebeckite and aegirine-riebeckite keratophyres, tuffs of these rocks, and tuffaceous lavas with strata of andesitic and dacitic porphyrites. The total thickness of these rocks is around 1000 m.

Effusions of basic and intermediate rocks continued here also in the Middle Carboniferous. Tuffs and tuffaceous lavas prevail in the upper part of the column. The thickness of Middle Carboniferous rocks is 1300-1500 m.

Middle Carboniferous rocks are overlain with distinct disconformity by Upper Carboniferous rocks, which, according to A. A. Rozenko in the lower part are represented almost exclusively by basic effusives, and in the upper part by an intensive interstratification of mottled tuffs, tuffaceous sandstones, conglomerates and breccias, and occasionally shale and quartz porphyries. The thickness of Upper Carboniferous deposits is around 1200 m.

TABLE 1. Juxtaposition of Stratigraphy of Geologic Zones of the Eastern Balkhash Region

Age	Balkhash Zone[1]	Bakanass Zone[2]	Tarbagatay Zone[3]
Permian		Tuffs, intermediate and acid effusives; at the top - flows of trachytic porphyries. Thickness up to 1200 m.	
		Hiatus - Disconformity	
Upper Carboniferous		Diabasic porphyrites, motley tuffs, black shales and siltstones, black limestones. At the top, strata of acid effusives. Thickness up to 1200 m.	

[1]According to V. V. Galitsky, S. N. Golyshev, and B. Ya. Ponomarev. [2]According to A.A. Rozenkrants, M. B. Sta[illegible] V. V. Galitsky, and S.N. Golyshev. [3]According to S.N. Golyshev, V.P. Ponikarov, A.I. Olli, and B.Z. Uretsky.

TABLE 1. Juxtaposition of Stratigraphy of Geologic Zones of the Eastern Balkhash Region (Continued)

Age	Balkhash Zone[1]	Bakanass Zone[2]	Tarbagatay Zone[3]
Upper Carboniferous (concluded)		Fauna: Pseudoesteria cebennensis (grand Eury). Flora: Paracalamites, striatus, Schmall., P. vicinalis Radz., P. cf. kutorgaj Geinitz., Cardioneura sp. Calamites gigas. Brongn., Noeggerathiopsis Theodorii Zal., N. cf. subangusta Zal. Walchia kassagatschica Tschirkova.	
	Hiatus - Disconformity		
Middle Carboniferous		Paleobasalts, diabasic porphyrites, sandstones, graywackes. At the top, andesitic porphyrites, tuffs, and tuffaceous lavas of acid effusives. Thickness up to 1500 m. Flora: Noeggerathiopsis Theodorii Zal., Phylloteca sp., Lepidodendron sp.	
	Hiatus - Disconformity		
Lower Carboniferous	Conglomerates, sandstones, calcareous sandstones, more rarely limestones. Interbedded with acid effusives. Thickness up to 1000 m. Fauna: Dalmanella sp., Leptaena sp. Productus (Productella) sp., Reticularia sp., Flora: Bergeria regularis Schmall., Pelecipodae, near to Myalina amaena Kon.	Tuffs, tuffaceous breccias, tuffaceous agglomerates, diabasic and andesitic porphyries. At the top - aegirine-riebeckite keratophyres. Thickness up to 2500 m. Hiatus - Disconformity Tuffs of acid effusives, albitophyres, felsite-porphyries, quartz porphyries, more rarely - porphyrites; in the basal part - conglomerates. Thickness up to 1000 m.	Tuffs, tuffaceous sandstones alevrolites, quartz porphyries at the top - aegirine-riebeckite keratophyres. Thickness up to 1000 m. Flora: Mesocalamites ramifer (Stun.) Hirm. Hiatus - Disconformity Conglomerates, sandstones, siltstones, coaly shales, limestones. In places few beds of porphyrites. Thickness up to 1000 m. Fauna: Productus fernglanensis Well., P. simpsoni Well., P. cf. burlingtonensis Hall., Chonetes kingnirica Nal., Spirifer lausianensis Roul, S. grimesi Hall., S. cf. tornacensis (Kon.). Lamellispirifer roemerianus (Kon.).
		Hiatus	
Upper Devonian	Sandstones, calcareous sandstones, tuffaceous sandstones, limestones. Thickness from 700 to 1100 m. Fauna: Productus opuctus Hall., P. sp., Chonetes cf. hardensis Phill., Cirtospirifer sp., C. cf. semisburgensis Nal., Theodosia sp., T. ex gr. anossofi Vern., Athyris angelica var., rulica Nal., Stropheodonta ex gr.	Plagioclase and hornblende porphyrites, more rarely albitophyres and tuffs. Few beds of polymictic sandstones, siltstones, and shales. Lenses of limestones. Thickness up to 2800 m. Fauna: Chonetes cf. nana Ver., Striatorproductus sericeus Bech., Reticularia finibriata Cous., Schizophoria impressa Hall., Spirifer (Cyrtospirifer culeifer) Hall., et Clarke S. (Lamellispirifer) cf. cuncur Nal., Schuchertella	Conglomerates (some varieties consist of granules only), sandstones, siltstones, shales Beds of tuffaceous sandstones, lenses of limestones. Thickness up to 1200 m. Fauna: Lamellispirifer novosibircus (Toll), L. vasinensis var., mucronatoides Rzon., Spirifer (Cyrtospirifer) aff. lebedianus Nal., Athyris angelica Hall., Adolfia cf. ciczak Roem., Atrypa sp. Camaratoechia sp.

TABLE 1. Juxtaposition of Stratigraphy of Geologic Zones of the Eastern Balkhash Region (Concluded)

Age	Balkhash Zone[1]	Bakanass Zone[2]	Tarbagatay Zone[3]
Upper Devonian (concluded)	nobilis M'Coy., Camarotoechia sp.	cf. umbraculum Schloth, Lamellispirifer posteriss Hall., et Clarke Plicatifera simplicior Widborne.	
Middle Devonian	Fine-grained sandstones, shales, limestones; few beds of tuffaceous sandstones. Thickness up to 1400 m. Fauna: Acrospirifer frequens Bubl., Spirifer cf. cardulensis Scht., S. cf. irbitensis Tschern., Stropheodonta ex. gr. nobilis M'Coy., S. cf. interstrialis Phill.	Silicified and calcareous sandstones, tuffaceous sandstones, limestones. At the top - beds of porphyries, porphyrites and tuffs of these rocks. Thickness up to 2500 m. Fauna: Atrypa tubolcostata Paec., Lamellispirifer ligus Owen, Favosites sp., Acrospirifer cheichel Kon., A. freguens Bubl., Streptorhynchus devonicus Orb., Streptolasma rectum Hall., Chierurus cf. quenstedti Barr.	Greenish-gray and red conglomerates, red sandstones, conglomerates consisting of granules, beds of effusives and tuffs. Thickness up to 500 m. Fauna: Spirifer (Euryspirifer) cf. ali Nal., S. cf. posterus Hall., Euryspirifer audaculus Cour., Atrypa, ex gr. reticularis Linné.
Lower Devonian	Gray and greenish-gray sandstones with siliceous or carbonaceous cement, polymictic sandstones, beds of black shales. At the top - coal seams. Thickness up to 2500 m. Fauna: Acrospirifer primaevus Stein., A. sp., Spirifer daleidensis Stein., S. herciniae, Eospirifer sp., Delthyris cf. tira Barr. Atrypa sp., Schuchertella sp., Chonetes sp., Avicula sp.	Gray and greenish-gray sandstones with siliceous and calcareous cement, polymictic sandstones, beds of black shales. Thickness up to 2500 m. Fauna: Atrypa reticularis L., A. cf. animaspus Eichw., Athyris sp., Strophomena stephani Barr., Histerolites speciosus (Schloth), Spirifer sp. Eospirifer sp.	Deposits not known.

Upper Carboniferous rocks are overlain by a distinct disconformity of Permian deposits beginning with basal conglomerates. These deposits are divided by a disconformity into two sections:

1. The lower section, represented by tuffogenic rocks: tuffaceous conglomerates, tuffaceous lavas, and tuffs of porphyrites and acid effusives; the total thickness is around 1000 m.

2. The upper section represented by flows of albitophyres, trachytic porphyries and acid effusives and biotite plagioporphyries. Tuffaceous lavas, tuffs and lava breccias are less common; the maximal thickness of this series is up to 200 m.

Acid effusives lie almost horizontally. The effusion occurred under conditions of a considerable consolidation of the area.

Thus in the Bakanass zone the long period of time from the Middle Devonian up to the Permian is characterized by vigorous and almost continuous volcanic activities, as well as by intensive uneven vertical movement in both directions, with the prevailing tendency toward the sinking. This is confirmed by the alternation of basic (predominant) and acid effusives, and also by the presence of huge accumulations of volcanogenic deposits.

It can be assumed that, against a background of general sinking, brief uplifts occurred at the end of the Late Devonian, in the Early Carboniferous and at the end of the Late Carboniferous. Between the Upper Carboniferous and Permian a phase of intensive folding

occurred which was vigorous, but evidently of a short duration, and was accompanied by granitoid intrusion. In the Permian period, especially beginning with the second half of the Early Permian period, the tendency toward uplift acquired a more steady character. The area entered the stage of the subplatform development.

The developments of the Balkhash and Tarbagatay zones during the Hercynian stage proceeded in the same direction; however, there were differences in some details. At the beginning of the Middle Devonian in the central part of the Tarbagatay zone the formation of a trough began, which stretched and opened in a northern direction. Volcanogenic beds of the Eifelian and, evidently, partly of the Givetian stages were accumulating in this trough. According to S. N. Golyshev's data these beds are built predominantly of interstratified plagioclase, pyroxenoplagioclase and diabasic porphyrites. Tuffs and tuffaceous conglomerates with gravels of the surrounding rocks are much less common. The total thickness of these deposits is around 900 m.

Higher in the geologic column only sedimentary, mostly terrigenous, rocks occur of comparatively small thicknesses. There is almost no difference between thicknesses and facies of the Upper Devonian and Lower Carboniferous sediments developed in the Balkhash and Tarbagatay zones. A somewhat intensified siliceous character of the Upper Devonian sediments within the trough might be a result of the proximity to volcanic sources.

Thus, the internal trough in the Tarbagatay zone, which had begun to form almost simultaneously with the Bakanass zone of downwarping and probably even somewhat earlier, completed its specific development not later than the beginning of the Upper Devonian epoch. However, it is also possible, that the downwarping in both zones began at the same time and was an expression of the same process, but the character of the later development turned out to be different.

Somewhat different conditions were within the Balkhash zone. According to the data of V. V. Galitsky, S. N. Golyshev, and B. Ya. Ponomarev, the geologic column from the Lower Devonian up to the Tournaisian is almost continuous and is characterized by terrigenous sediments with admixtures of tuffogenic and siliceous materials. Only local, very small hiatuses are recorded, marked by thin strata of intraformational conglomerates composed of small-size gravels. Deposits of deep water are also absent. It can be considered that this zone was subject to a slow and relatively uniform sinking which was almost completely compensated by the accumulation of shallow sea deposits. The presence of the tuffogenous and siliceous materials in terrigenous sediments is evidently associated with the proximity of the volcanic centers of the Bakanass zone. However, it is worth mentioning that in the northern Balkhash zone, west from the meridian 78E, the internal trough was in existence, in which, beginning with the Upper Devonian and up to the Middle Carboniferous, the accumulation of a thick series of deposits of geosynclinal type took place.

V. F. Bespalov [2] presents the following compound profile of deposits of the Sayak District:

D_3^2 - Sandstones.
Unconformity and erosion.

C_1t_1 - rocks of bright colors: tuffaceous sandstones, keratophyres and dacites, agglomerates; in the top section - siliceous tuffites (shales), tuffs, brownish-green ceratophyres porphyrites, conglomerates, sandstones, siltstones with poorly preserved fauna of the type Spirifer ex. gr. tornacensis Kon., Productus ex. gr. semireticulatus Nart.; thickness up to 1200 m.

C_1t_2 - conglomerate-sandstones, tuffs, sandstones, siltstones, limestones with fauna of the type Spirifer forbesi N. et. P., Brachythyris suborbicularis Hall.; thickness up to 400 m.

C_1v_1 - sandstones, conglomerates, argillites, coaly shales, in places coaly and ferrous laminae. Flora and fauna (poor) corresponding to the Lower Visean; thickness 150-200 m.

C_1v_2 - $+C_1n$ - Sayak formation. Transgressively, on different horizons, a green sedimentary-effusive formation, having a thickness up to 2500 m., rests. The top section includes Spirifer mortonanus Nill., Productus craufordus villensis Well., Echinoconchus elegans M'Coy, Productus cf. produs Rot. and others. The cross section usually begins with conglomerates with pebbles of intrusive and other rocks. Horizons of conglomerates occur also inside the formation. Tuffaceous sandstones, tuffs and horizons of acid and intermediate lavas prevail in the cross section. In the upper part, limestone occurs in places.
Slight disconformity and erosion.

C_2 - grayish-green pyroxenoplagioclase and andesitic porphyrites composing the core of the Sayak syncline.

It is characteristic, that eastward, at a small distance from the Sayak Trough, Tournaisian sedimentary deposits overlie with a perfect conformity sandstones of the upper section of the Upper Devonian rocks. The Sayak formation is absolutely absent here, as well as all other later pre-Tertiary deposits.

Of a great importance is a very complicated question of the role of deformations involving fractures in the process of the formation and development of geologic zones under discussion. It was indicated above, that in the Middle and Upper Devonian, the Uzhbulak and Tyulkulam-Sasykkul fractures formed boundaries of these zones. Evidently, the same fractures served as the main channels of supply of volcanic material filling up the Bakanass zone of downwarping. This is confirmed by the uniformity of composition of synchronous effusives distributed on the large areas adjacent to the said fractures, as well as by tremendous thicknesses of volcanic masses in the immediate vicinity of fractures. If one assumes that the Bakanass zone warped down without the appearance of deep fractures in marginal areas of the zone, and that the zone of downwarping was filling up from the interior toward the marginal areas and that fractures, serving as channels for vigorous effusives, were situated in the central, axial, portion of the zone of downwarping, then one has to assume that volcanic deposits of a quite incredible thickness were accumulated here up to 20 km. in the Devonian only.

In the Lower Carboniferous boundaries of the Bakanass zone shifted somewhat: the north boundary - to the northeast, the south one - to the southwest. The area of this zone expanded at the expense of the two neighboring zones, and in the process of intensive downwarping, accompanied by fault movements, areas of relative stability became included. The stable boundaries of areas where these new movements took place occurred along the fractures: the Ayaguz-Urdzhar fracture in the north, and the Main Dzhungarian fracture in the south. Apparently, these fractures also served as channels for transportation of effusive material into the Bakanass zone of downwarping. They are the largest deformations involving fracturing in the region and stretch for hundreds of kilometers. It seems that these fractures are of a younger age; in any case, they were rejuvenated in the Cenozoic, because the Hercynian Bakanass zone of downwarping territorially coincides with the Alpine depression which is expressed in the contemporaneous topography and is bounded by the said fractures.

It is interesting that the Ayaguz-Urdzhar and the Main Dzhungarian fractures are not parallel to the Ushbulak and Tyulkulam-Sasykkul fractures, but are at an acute angle (on the order of 15-18°). This is the evidence of a certain change in the direction of tectonic movements during the period of the formation of Hercynian structures.

Thus, the boundaries of the Bakanass zone were not steady, but shifted between the Ushbulak to the Ayaguz-Urdzhar fractures in the north and between the Tyulkulam-Sasykkul and the Main Dzhungarian fractures in the south. Those sections of the earth's crust enclosed by these boundaries and immediately influenced by great deformations involving fractures, and those which were subject to fractures of the secondary order, should be subject to maximum tectonic stresses and form the most mobile sections.

Since the deep seated fracture is expressed neither by a single line of the tectonic deformation, nor by a fracture line, but by a complicated zone of tectonic deformations, it should be assumed that the mobile sections just described represent the zones of deep seated fractures. The four great fractures described above served as linear manifestations of deep-seated fractures at certain stages of their developments. We shall apply the name South-Tarbagatay Zone to the northern zone lying between the Uzhbulak and the Ayaguz-Urdzhar fractures, and the name North-Dzhungarian Zone to the southern zone, bounded by the Tyulkulam-Sasykkul and the Main Dzhungarian fractures (Fig. 2).

Also fractures of the northeastern direction are developed in the Eastern Balkhash region. They are especially characteristic for the Bakanass Zone. However these fractures are of the secondary importance: they are associated with the stages of the consolidation of the whole region and nowhere do they occur as boundaries of geologic provinces.

A certain regularity is also recorded in the intrusive magmatic activity. According to V. G. Chuikova's data three intrusive complexes of different ages are distinguished within the Eastern Balkhash region.

1. Intrusions of Ultrabasic Rocks. They are represented by peridotites, dunites, pyroxenites and, to a large extent, by serpentines. It should be mentioned that some workers consider these intrusions to be of Hercynian time, others consider them to be more ancient.

2. Upper Carboniferous Intrusions of Granodiorites. This complex includes a range of different rocks - from biotite granites up to diorites. However, granodiorites and adamellites (quartz monzonite) form the main intrusive facies. The Upper Carboniferous age of the complex is established rather accurately on the basis of the low and upper age limits. Intrusions of this complex penetrated and transformed into hornfels the Upper Carboniferous deposits containing flora. The upper age limit is established by the fact that these intrusions are overlain by the basal strata of the Lower Permian tuffaceous agglomerates containing fragments and gravels of the granodiorites.

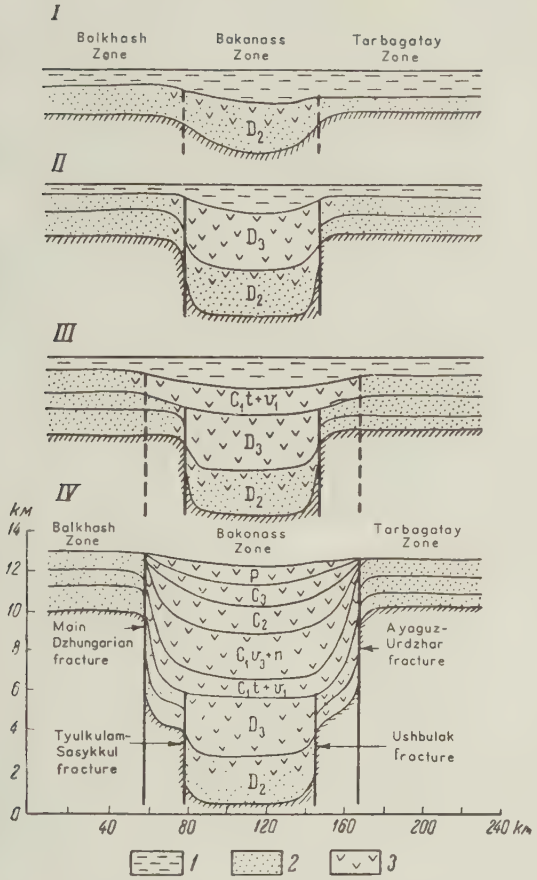

FIGURE 2. Diagram of the structure-facies zone development of the Balkhash area. (1) Sea basin; (2) Sedimentary deposits; (3) Volcanic formations

I. End of the Middle Devonian.
II. End of the Late Devonian.
III. Middle of the Visean.
IV. End of the Early Permian; horizontal scale 1/10 the vertical.

3. Permian Intrusions of Granites. These intrusions broke through Low Permian deposits. They are formed by many varieties of granite, but leucocratic and alkaline granites are prevailing. The latter, apparently, represent the latest phase of the complex. Some granitoid intrusions, which undoubtedly are associated with the Hercynian stage, cannot be divided in more detail. Apparently, their greatest part belongs to the Permian intrusive complex.

The following regularities in the distribution of intrusions were found:

1. Ultra-basic intrusions are known only in two sites of the Dzhungarian zone of deep-seated fractures. Their emplacement marked the stage of the geosyncline formation which immediately followed the first pouring out of basic effusives. From this standpoint, there are more reasons to consider these intrusions to be of the Hercynian stage.

2. Upper Carboniferous intrusions of granodiorites are located exclusively in the southwest part of the Bakanass zone, near to the Tyukulam-Sasukkul Fault. Their emplacement is associated with the tectomagmatic phase which is characterized by a rather intensive folding and the beginning of the consolidation of the territory of the Bakanass zone (between the Carboniferous and Permian).

3. Permian intrusions of granites are not strictly associated with any particular area. A considerable part of intrusive massifs of this complex is recorded in the South-Tarbagatay zone of deep seated fractures.

Other massifs, occurring in all zones, in one way or another are usually associated with great fractures. Apparently, the emplacement of intrusions of this complex took place under conditions of a considerable consolidation of all the territory of the Eastern Balkhash region.

The Kotbar granite massif presents an exception in this regard, since its association with great fractures was not established. However, this is possibly due to the insufficient investigation of the area.

The problem of the metallogeny of distinguished zones can be considered to be of special importance. Here the following regularities were established:

1. Occurrence of ores of lead and zinc, nickel and cobalt, chromium and titanium is associated exclusively with mobile zones of deep seated fractures. No occurrences of these metals in the East Balkhash region were recorded outside the above zones.

2. Occurrence of the ores of rare metals - tungsten, molybdenum, and tin - is associated with granites of the Permian intrusive complex and come only within the Tarbagatay and Balkhash zones, predominantly in their central sections.

3. Occurrences of copper and iron are mostly associated with zones of deep seated fractures and with the marginal areas of the Tarbagatay and Balkhash zones (the latter in a smaller degree). However, there are also small separate copper ore emplacements in the Bakanass zone.

Patterns in metallogeny, established for the Eastern Balkhash region, for the time being, have to a considerable extent only an empirical character and certainly cannot be applied to larger territories. But it should be stressed that in the region under discussion these regularities are very clearly manifested.

TABLE 2. Juxtaposition of Structural-Facies Zones and Zones of Deep-Seated Fractures in the East Balkhash Region

Characteristic Features	Structural-Facies Zones			Zones of Deep-Seated Fractures	
	Tarbagatay Intrageanticline	Bakanass Intrageosyncline	Balkhash Intrageanticline	South Tarbagatay Zone	North Dzhungarian Zone
The cycle of sediments accumulation	Middle Devonian - Lower Carboniferous (Tournaisian + Lower Visean)	Devonian-Permian	Devonian-Lower Carboniferous ($C_1t + v_1$)	Middle Devonian - Lower Carboniferous ($C_1v + n$)	Devonian - Lower Carboniferous ($C_1t + v_1$
Facies	Sedimentary (shallow sea), very seldom volcanic	Volcanic, very seldom sedimentary. Earlier than the Visean - marine conditions; from the Visean-Namurian up to the Upper Carboniferous - marine and continental, in the Permian - continental	Sedimentary (shallow sea), close to volcanic hearths - voluminous tuffogenous material	Mixed volcanic and sedimentary. Much coarse clastic material	Mixed volcanic and sedimentary
Thickness of deposits in m.: (a) can be juxtaposed (Middle Devonian-Lower Carboniferous)	3,700	8,800	3,500	3,700 - 5,000	3,500 - 6,000
(b) total	3,700	12,700	5,000	up to 9,000	up to 10,000
Intrusions	Permian granites	(a) Upper Carboniferous Granodiorites (b) Permian granites	Permian granites	Permian granites	(a) Ultrabasic intrusions (b) Permian granites
Ores occurrence	Rare metals, copper, and iron	Copper and iron	Rare metals, copper, and iron	Polymetals, nickel, copper, and iron	Chromium, nickel, cobalt, copper, and iron

All the material presented above indicates that each of the zones distinguished in the Eastern Balkhash region was characterized by specific conditions of the development during the Hercynian stage. These conditions determined the distribution of facies and thicknesses, as well as a real distribution of magmatic activities and metallogeny. Correspondingly, each of the zones has all the indications of a structural-facies zone whereas the Tarbagatay and Balkhash structural-facies zones are characterized by the geanticlinal process of development, and the Bakanass zone, by the geosynclinal process.

Studies of the process of development of the Bakanass structural-facies zones from the Middle Devonian to the Permian reveal a complete cycle of the formation of the clearly outlined Hercynian geosyncline: intensive downwarps, associated with the appearance or rejuvenation of great deep-seated fractures; vigorous marine ejection of basic effusives, and to the eruptions of acid and alkaline lavas; the intrusions during the last stage of the geosyncline's existence, associated with the folding; and the final effusions of Permian lavas of trachytic porphyries, occurring under conditions of considerable consolidation.

If this is so, then the Bakanass structural-facies zone is a completely independent intrageosyncline bordering on the northeast and the southwest by similarly independent Tarbagatay and Balkhash intrageanticlines. This shows in turn that the one Hercynian Dzhungarian-Balkhash intrageosyncline could not exist. Probably, it would be more right to talk about the existence of the Dzhungarian-Balkhash Hercynian geosyncline region or system.

REFERENCES

REFERENCES

[1] Bespalov, V. F., THE DZHUNGAR-BALKHASH HERCYNIAN GEOLOGICAL PROVINCE, PROBLEMS ON THE GEOLOGY OF ASIA. [DZHUNGARO-BALKHASHSKAYA GERTSINSKAYA GEOLOGICHESKAYA PROVINTSYA, VOPROSY GEOLOGI AZI]. Akademya Nauk SSSR, 1954. Vol. 1.

[2] Bespalov, V. F., THE MIDDLE PALEOZOIC OF THE DZHUNGAR-BALKHASH INTRA-GEOSYNCLINES. [SREDNY PALEOZOY DZHUNGARO-BALKHASHSKOY INTRA-GEOSINKLINALI]. Sovietskaya Geologya, 1956. Sbornik 52.

[3] Bespalov, V. F., UPPER PALEOZOIC OF WESTERN KAZAKHSTAN. [VERKHNY PALEOZOY VOSTOCHNOGO KAZAKHSTANA]. Sovietskaya Geologya, 1956. Sbornik 52.

[4] Nekhoroshev, G. V., NEW DATA ON THE STRATIGRAPHY OF THE UPPER PALEOZOIC OF THE SOUTHERN SLOPE OF THE DZHUNGAR ALTAU. [NOVYE DANNYE PO STRATIGRAFI VERKHNEGO PALEOZOYA YUZHNYKH I ZAPADNYKH SKLONOV DZHUNGARSKOGO ALATAU]. All Union Geological Scientific Research Institute, Gosgeoltekhizdat, 1956. No. 4..

[5] Nekhoroshev, G. V., STRATIGRAPHY AND MAGMATISM IN THE UPPER PALEOZOIC OF THE SOUTHERN SLOPE OF THE DZHUNGAR ALTAU. [STRATIGRAFYA I MAGMATIZM VERKHNEGO PALEOZOYA YUZHNYKH SKLONOV DZHUNGARSKOGO ALATAU]. Avtoreferat dissertatsi, All Union Geological Scientific Research Institute, Leningrad, 1957.

[6] Ponikarov, V. P., NEW DATA ON THE STRATIGRAPHY OF NORTHEASTERN BALKHASH AREA AND THE NORTHWEST PART OF WESTERN TARBAGATAY. [NOVYE DANNYE PO STRATIGRAFI SEVERO-VOSTOCHNOGO PRIBALKHASHYA I SEVERO-ZAPADNOY CHASTI ZAPADNOGO TARBAGATAYA]. Trudy MGRI, 1954. Vol. 26.

[7] Staal, M. B., ON THE STRATIGRAPHY OF THE UPPER CARBONIFEROUS DEPOSITS OF THE NORTHEAST BALKHASH REGION. [K STRATIGRAFI VERKHNEKAMENNOUGOLNYKH OTLOZHENY SEVERO-VOSTOCHNOGO PRIBALKHASHYA]. Sovietskaya Geologya, 1956. Sbornik 52.

Review Section

Teodorovich, G. I., A CONTRIBUTION ON THE ORIGIN OF LIMESTONES AND DOLOMITES.[1] Transactions of the Petroleum Institute of the Academy of Sciences of the USSR, Vol. V, 1955. Translated by Mark Burgunker.

The exceptionally great scope of geological exploration in the USSR, which the Five Year Plans have entailed, has led to the formulation and attempted solutions of numerous and many-sided problems in the mineralogy, petrography, and geochemistry of all types of sedimentary rocks and economic minerals. It is only natural, therefore, that the new achievements in this field should also involve new results in the study of limestones and dolomites.

The new achievements (in the present paper we refer only to literature published prior to 1953) in the development of methods of investigating limestones and dolomites can be summarized as follows:

(a) The identification of the calcite in dolomite by etching polished thin sections with 2% HCl solution [1].

(b) The development of thermal methods (the investigation of the influence of admixtures of NaCl and other salts of the alkali metals on the decomposition of dolomite, the introduction of new methods of thermal analysis of the carbonates, etc.), and the calculation of the dolomite and calcite contents in carbonate rocks by measuring the area bounded by differential thermal analysis curves [2, 3, 9, 15, 48, 49].

(c) The classification of carbonate reservoir rocks on the basis of pore structure, and the relationship between pore structure and permeability -- these data obtained from thin section studies [38, 45].

(d) The successful utilization of x-ray and spectrographic methods in the study of the carbonate minerals in sedimentary rocks.

(e) The identification and study of animal remains, layering, and fissuring in finely granular calcareous rocks by means of light oil saturation methods [6].

(f) The development and reevaluation of methods of studying the rock-forming properties of carbonate minerals [36, 46].

The experimental investigation of the development of dolomite was pushed in two directions:

1. The solubility of dolomite under various conditions was studied (O. K. Yanatiev studied the system (Ca, Mg)CO_3, SO_4-H_2O at 25^o and P_{CO_2} = 1 atmosphere).

2. The production of dolomite and magnesite in the laboratory, under conditions similar to those under which these rocks are produced in nature, was undertaken. In addition, experimental investigations of the formation of spherulites and oölites were carried out [19]; the formation of finely granular dolomite was also investigated experimentally [23].

The limestones and dolomites have been classified with respect to their mineralogy, with respect to petrographic structure, and with respect to their genesis. Further, a series of classifications was proposed for the clay-carbonate rocks which belong to the series limestone-dolomite clay [46].

The very considerable advances which were made in the study of the rock-forming role of algae are the result of a great program of petrographic investigations, extremely detailed studies of the physical-geographic conditions under which shallow water limestones are formed, and a more explicit formulation of the problem of cycles and rhythms in the deposition of limestones and dolomites [17]. In addition, the fundamental genetic characteristics of the structure of calcium carbonate and dolomite deposits have been specified, and a more intensive approach to the problem of recent marine and lacustrine carbonates has developed.

The fundamental stages in the evolution of the petrographic structure of calcium carbonate [39] are the following: (1) microgranular calcium carbonate, precipitated from the waters of the basin of deposition; (2) oölites; (3) calcareous crusts and incrustations; (4) syngenetically recrystallized calcium carbonate; (5) calcium carbonate crystallized on the walls of voids; (6) epigenetically recrystallized calcium carbonate.

The fundamental stages in the development of the petrographic structure of dolomite [40, 41] are the following: (1) irregular grains (pelitomorphic) precipitated from the waters of the basin of deposition; (2) replacements consisting of more or less regular and somewhat larger grains than (1); (3) linings of voids

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[1] K voprosu o proiskhozhdenii osadochnykh izvestkovo-dolomitovykh porod.

made up of (occasionally hemispherical) microaggregates of grains with cruciform extinction; (4) incrustations; (5) concentric oölites; (6) granular and recrystallized, because of metamorphism; (7) "secondary" dolomite, which is the result of the recrystallization of the pelitomorphic rock on the bottom of the basin of deposition.

Lithological research, during the past several years, has devoted a considerable amount of attention to the problem of the development of dolomitic sediments [5, 10, 17, 18, 21, 22, 24, 29, 34, 37, 39-43, 45, 46]. This problem was attacked by means of investigations of ancient and recent carbonate sediments.

1. The fact that the solubility of $MgCO_3$ approaches that of $CaCO_3$ as the mineralization of the dissolving water increases was indicated as a cause of the precipitation of dolomite in 1941 [5].

2. The selective nature of replacement dolomitization (in microgranular $CaCO_3$) was established, and it was demonstrated, on the basis of studies of ancient lagoonal dolomites [37, 43, 46], and physical-chemical laboratory investigations [52, 53], that the reaction between $CaCO_3$ and $MgCO_3$ -- in sea water in which concentration tends to increase because of evaporation -- goes to completion when the water is saturated with respect to $CaSO_4$ and not with respect to $MgSO_4$.

3. The calcareous and dolomitic sediments of Lake Balkhash were investigated, and it was shown that the pelitomorphic dolomite here is a primary precipitate from solution [20, 21, 24]; the dolomitization parameters for the waters of Lake Balkhash were also specified by these investigations. N. M. Strakhov wrote in 1951, however, that the accumulation of dolomite in the carbonate silts of Lake Balkhash is associated with the chemical precipitation of calcium carbonate and the basic salt of magnesium carbonate, and that the latter is quickly converted to dolomite by diagenetic processes.

4. The following facts were established for the Kungurian of the Ishimbai Cis-Urals [32]: (a) the carbonate in the dolomitic rocks consists of dolomite with an admixture of calcite, but magnesite is entirely absent; (b) the carbonate component of the anhydrite-carbonate rocks is between 95% and 100% dolomite, with an admixture of calcite and, less frequently, magnesite; (c) the carbonate component in the anhydrites consists of dolomite with small amounts of calcite and magnesite; (d) magnesite is the main carbonate component of the halites; (e) the carbonates in the sulfate-carbonate facies, the anhydrites, and the halites are primary pelitomorphic chemical precipitates.

5. G. I. Teodorovich [43, 46] identified the following facies among the dolomites and dolomitic limestones of the Carboniferous and lower Permian of the Volga-Urals Province: (a) normal marine facies which include deposits laid down in shallow waters and in the middle depths of the cratonic shelf; (b) deposits laid down in high-salinity sea water, lagoonal embayments, and periodically drying calcareous flats; (c) deposits laid down in high-salinity lagoonal environments.

We can then summarize the data on the problem of the genesis of dolomitic and, to some extent, the problem of the genesis of magnesitic deposits, which Soviet petrographers have accumulated in the course of their studies of the Paleozoic carbonates in the following manner:

1. Two fundamental types of dolomite-- the normal salinity marine and the high salinity lagoonal-- are to be distinguished. The normal salinity calcareous dolomites and dolomitic limestones are the products of the replacement of the calcium carbonates in bottom silts. The chemical precipitation of primary pelitic dolomite or sulfate-dolomite accompanies the replacement of calcium carbonate in high salinity lagoonal environments, however. The limestones and dolomites which form in very saline seas, or in atolls, constitute a third and intermediate group. The limestones and dolomites which form as primary pelitic precipitates in continental lakes in arid regions constitute a fourth group. In general, the role of primary (chemical) dolomite in the sedimentary cycle increases as one moves back through time.

2. The following may be considered the most important factor in the deposition of dolomite:

(1) The cation and anion (especially the Ca^{++} and Mg^{++}) composition of the dissolved salts; (2) the mineralization of the water; (3) the pH value; (4) the partial pressure of the CO_2 (the increased carbon dioxide partial pressure found in bottom silts promotes the precipitation of dolomite); (5) the temperature of the water; (6) the rH profile in some environments[sic].

3. The deposition of dolomite is associated with the approach to equality of the solubilities of $CaCO_3$ and $MgCO_3$, and the increase in the concentration of the Mg^{++} ion, which are consequent upon an increase in the mineralization of sea water; the deposition of dolomite is also promoted by an increase in the temperature of the water, or a change in the composition of the dissolved salts such that an excess of $MgCO_3$ appears in the bottom silts. Slow, warm bottom currents frequently play an

important role in the deposition of (marine) replacement dolomites; in other cases, the $(NH_4)_2CO_3$ produced in the decomposition of organic tissue, and the $MgCO_3$ of calcareous and magnesian shells and skeletons, contribute to the dolomite deposition. Incomplete replacement of limestone by dolomite is characteristic of the normal salinity marine environment.

The primary pelitic dolomites are precipitated in the highly saline waters of lagoons or other marine embayments; the increased temperature and the shallowness of the water also facilitate the precipitation. The precipitation of dolomites in the seas of the geologic past, apparently, was more widespread, inasmuch as the partial pressure of the CO_2 in the atmosphere was greater. Waters which carry dissolved $CaCO_3$ begin to enter lagoons when the waters of the latter are saturated with respect to $CaSO_4$, and the precipitation of a variegated primary dolomite-anhydrite deposit begins. The precipitation of $MgCO_3$ in the form of magnesite, or magnesite and calcium carbonate, begins when the waters of a lagoon approach saturation with respect to NaCl, inasmuch as dolomite is unstable in these conditions. The waters of the lagoon, however, can also hold a considerable amount of $MgSO_4$ in solutions, under certain conditions.

We can distinguish the following fundamental genetic types of dolomite: (1) primary pelitic deposits; (2) widely occurring syngenetic replacement deposits which include (a) early diagenetic deposits, and (b) late diagenetic deposits; (3) epigenetic dolomites which include (a) replacement deposits, and (b) residual leaching products.

The data on the deposition of calcium carbonate, dolomite, and (to some extent) magnesite in the silts of Recent seas and lagoons have been presented and analyzed in the publications of S. V. Bruyevich and collaborators, and N. M. Strakhov and collaborators. These publications, however, give different solutions of the problem.

Bruyevich sees the approach to equality of solubility for $CaCO_3$ and $MgCO_3$, with the increasing mineralization of sea water, as the fundamental reason for the deposition of dolomite [5].

Strakhov has expressed various views on the reason for the deposition of dolomite. In a lengthy publication which appeared in 1951, he points to biological processes and the mineral products of biological processes as the fundamental source of chemical dolomite in normally saline marine waters, and to chemical reactions which involve $MgSO_4$ as the source of magnesite in lagoonal waters with high salinity.

Siliceous deposits, stylolites, and lens-like inclusions of calcium sulfate are the characteristic by-products of the deposition of a number of types of carbonate facies. The structural characteristics of the siliceous deposits have been studied and specified; four types of structure have been identified [6, 46]: (a) early diagenetic structures; (b) middle diagenetic structures; (c) late diagenetic structures; (d) epigenetic structures. The epigenetic structure, as well as the diagenetic structure, can be used in the paleogeographic reconstruction of the basin of deposition.

The study of limestone deposits has led to an hypothesis about the origin of stylolitic surfaces; this hypothesis assigns a definite paleogeographic significance to such surfaces, and distinguishes three stages in their development [42].

Soviet lithology has been dealing with the concept of the geochemical sedimentary facies since 1933; the investigation of the place of carbonate formations and sedimentary carbonate minerals among geochemical facies commenced somewhat later [16, 18, 43, 44, 46].

Soviet geology has been engaged in an intensive investigation of the genetic and cyclical attributes of the deposition of carbonates [17, 29, 46, 50, 51], and many other investigators. Again, we have long since embarked upon the investigation of various types of sedimentary formations--petroleum-bearing formations, coal-bearing formations, flysch formations, etc. Most of these studies, however, have been carried out by tectonicists. Only A. V. Kazakov's work on phosphate facies (1939; 1950) and the works of V. I. Popov (1940; 1946), N. B. Vassovich (1940; 1951), and several other investigators have given us a more or less comprehensive treatment of these problems. There have been, also, significant achievements in the study of the influence of climate on the deposition of carbonates [24, 25, 28, 29, 45, 46].

The question of studying present-day carbonate sediments, in order to understand better the processes by which the carbonates of the geologic past were formed, was taken up in the course of the discussions which took place at the All-Union Conference on Sedimentary Rocks (N. M. Strakhov, L. V. Pustovalov, Yu. A. Zhemchuzhnikov, and others).

N. M. Strakhov's comprehensive monograph on the subject has some positive aspects, and a number of negative aspects. The positive aspects of the monograph include (1) an attempt to generalize the lithological data on the subject; (2) the broad range encompassed by Strakhov's framework of reference.

Strakhov's monograph, however, also

possesses the following defects: (1) an overemphasis on the role of "living matter" in the carbonate balance in nature; (2) an exaggeration of the organic and mechanically transported calcium carbonate components in Recent calcareous and dolomitic sediments, lack of emphasis on the role of chemical precipitation, and, in general, an overemphasis on the role of biological processes; (3) an entirely unjustified attempt to explain the distribution of carbonates in the oceans and other marine waters by a "dilution" of the former in terrigenous, siliceous, gypseous, or other suspended and dissolved matters; (4) an erroneous treatment of the problem of the genesis of the magnesium carbonates; (5) a completely unacceptable framework for the treatment of the precipitation of carbonate in marine and lacustrine waters in the chapter, "The fundamental laws of carbonate deposition in the geologic past"; (6) a complete lack of selectivity and objectivity in the treatment of carbonate deposition in ancient basins; (7) an especially erroneous line of analysis in the last two pages of the monograph-- in the section entitled "Similarities and differences between ancient and Recent processes of carbonate deposition"--where Strakhov stubbornly defends all of his assertions, which, at the present time, are hardly shared by any geologists. All of these issues are so important that we will examine them in detail below.

The primary problems in the study of limestones and dolomites are the following:

(a) The study of the distribution of limestones and dolomites in the major and minor cycles of sedimentation in cratonic regions, as well as in geosynclines, foredeeps, intermontane depressions, and similar tectonic basins with due regard to climatic and other conditions.

(b) A comprehensive lithologic and stratigraphic investigation of limestones and dolomites, particularly in their relations to associated formations, with due regard to tectonics, climatic, and other conditions.

(c) An investigation of the similarities among the carbonate rocks deposited at various stages of the sedimentary cycle, for the purposes of determining the extent to which the places of such rocks in the cycle are analogous each to the other, and determining the differences among the directions taken by sedimentary cycles.

(d) The solution of the problem of the development of the various types of economic deposits associated with carbonate sediments, the connection between such deposits, and the various facies of carbonate rocks, and thus a deepening and broadening of the scientific foundations of economic mineral exploration.

The scientific and practical significance of Soviet lithologic research for the understanding of the development of sedimentary carbonate minerals and rocks, and for economic mineral exploration, is great indeed. These facts compel us to treat the recent generalizations of data in this field with a maximum of objectivity.

The report of the Organizational Committee of the All-Union Conference on Sedimentary Rocks contains the following statement: "The comparison of ancient and recent sediments is not resorted to with sufficient frequency, and when it is resorted to, the methodology of comparative study is erroneous. N. M. Strakhov has developed a methodology for such comparative studies, and has demonstrated its applicability in his great monographic publications (Iron ore facies and their analogues in the geologic past and Limestone and dolomite facies in recent and ancient bottom sediments).

We shall examine only Strakhov's second monograph, which is mentioned in the report of the Organizational Committee as an example of comparative lithologic study.

The Treatment of Initial Materials and Empirical Data

Before we embark upon an examination of the fundamental ideas developed in Strakhov's book, let us consider the manner in which the author treats the data in the literature and the empirical data at his disposal. In Limestone and dolomite facies of recent and ancient bottom sediments (1951), experimental values for the activity of living organisms obtained in very small, isolated systems--in bottles, shallow layers of water saturated with calcium carbonates, between glass plates, etc.--are introduced into the analysis without any qualification whatsoever. The role of bacteria in the decomposition of shells also is overestimated; bacterial activity is indicated as the cause of the decomposition of crystalline, microgranular, and pelitic calcium carbonate in warm southern seas. A great body of data, accumulated in the course of investigations of the Paleozoic carbonates demonstrates, however, that the opposite is true--these carbonates carry a great abundance of undecomposed shells. Again, it should be pointed out that the proportions of detritus and silt are consequent upon the degree of agitation of the water--i.e., upon the specific characteristics of the total hydrodynamic regime of the basin of deposition; the fine calcium carbonate which is produced mechanically is a minor component of calcareous deposits, and not the major component which Strakhov imagines it to be.

The discussion of limestone and dolomite

facies in Recent sediments is characterized throughout by the assumption that calcium carbonates of organic origin, as well as calcium carbonates of mechanical origin, are dominant, and that chemically precipitated $CaCO_3$ is subordinate. This results from the fact that Strakhov falls back upon the conclusions of investigators (Thorp, Pia, Correns) who share his views. The results obtained by investigators who take the opposite view, and assign a major role to the chemical precipitation of $CaCO_3$ (Kazakov, Bruyevich, Heim, Bavendamm, and others) are ignored as if these results were never obtained; these investigators, however, also studied Recent sediments and carried out numerous laboratory experiments. One simply cannot suppress data which point in an opposite direction, as does Strakhov--if one does not agree with particular conclusions, one criticizes them.

The role of biological factors which directly influence the environment of deposition for dolomite is also exaggerated. The processes of dolomite deposition in present-day seas and oceans--the Caspian, the Atlantic, and elsewhere--are not treated in an especially objective manner; only areas of dense algal development are treated as areas of dolomite deposition.

Strakhov follows earlier investigators in drawing a sharp distinction between waters of the Caspian and Aral type, on the one hand, and waters of the Black Sea type, on the other, and then treats the carbonate balance of the Caspian in a manner which, again, is not especially objective. Thus, for example, the plot of carbonate content against salinity shown in Strakhov's Figure 112 (p. 260) is drawn without regard for the mutual relationship between the alkali reserve and the $CaSO_4$ concentration, the importance of which Strakhov stresses in his text. We know, of course, that a practically constant alkali reserve is associated with a sharp rise in the $CaSO_4$ concentration if the salinity of the water is less than 6%, and that the $CaSO_4$ concentration drops sharply if the salinity rises above 6%. In the last analysis, there is no "mutual connection between the $CaSO_4$ concentration and the alkali reserve"; there is no question, however, that there is a very intimate relationship between the alkali reserve and the pH values in the waters of the Caspian. This last fact shows that the pH in the waters of the lagoons and lakes of the Caspian-Aral Basin is determined by the salt concentrations, especially the concentrations of $MgCl_2$ and $MgSO_4$, and not by the magnitude of the alkali reserve, which grows with increasing salinity in the event that the pH decreases at the same time.

The plot in Figure 109 (p. 257) is just as arbitrary; this is a plot of the carbonate balance in the waters of the so-called "carbon-calcium basins," at the initial stages of increasing salinity. The $CaSO_4$ and alkali reserve ($CaCO_3$) curves do not show the inverse relationship which Strakhov asserts for them, inasmuch as the $CaSO_4$ concentration is not plotted for salinities less than 0. 6%. It is necessary, however, that the $CaSO_4$ concentration decline over the salinity range between 0 and 0. 6%; there is no evidence for such a decline.

We read, on page 27 of Strakhov's book, "As the mineralization of the solution increases, the salts themselves emerge as the dominant, decisive factor in the solubility of $CaCO_3$, and the role of CO_2 declines. The role of the CO_2 also declines as temperature increases." Previously, Strakhov had ignored these universally acknowledged facts completely; he noted them in his book, to be sure, but he then went on to classify basins of deposition with respect to the character of the alkali reserve (the soda type, with $Na_2CO_3 + MgCO_3 + CaCO_3$ in solutions; the magnesium carbonate type, with $MgCO_3 + CaCO_3$ in solution; the calcium carbonate type, with $CaCO_3$ in solution); the alkali reserve, however, is a secondary characteristic. If we recall that soda lakes have long since been regarded as a distinct type of basin, and that, in Strakhov's classification, almost all bodies of water fall into the calcium carbonate group, we can understand the sterility of his three-fold classification, in which the magnesium carbonate basins constitute a group which is at the same time very small and very heterogeneous. The artificial and practically trivial nature of Strakhov's classification is apparent immediately. Indeed, in Strakhov's classification all the oceans, open seas, land-locked continental seas, salt lakes of marine origin, and many continental lakes belong to the third, or "calcium carbonate class" of basin. This "type" of basin, according to Strakhov, is dominant at the present time and "this same hydrochemical [?--G. T.] type of basin was dominant on the surface of the earth in the geologic past, at a very early date--at least as far back as the end of Algonkian time."

Strakhov's assertion that the same "type" of hydrochemical regime dominated the surface waters of the earth since Algonkian time is incorrect; what is more important, however, is the fact that the "calcium carbonate class" of waters is an artificial category which includes all the waters which contain $CaCO_3$, irrespective of the role which this compound plays in the chemistry of the water. Strakhov's classification is based upon secondary characteristics, and therefore ignores the composition of the dissolved salts and the mineralization of the water--i. e., the fundamental chemical and genetic properties. This dreamed-up classification would actually

assign the water of a given basin to one class, and the water in the bottom sediments of the same basin to another class. We ask, therefore, how can we use Strakhov's scheme to classify that material which is of primary interest to geologists--bottom sediments?

The carbonate balance of the ocean is treated on the basis of Wattenberg's data for the Atlantic [29], with the difference that Strakhov's own inferences are given in the text on page 117. These inferences differ from Wattenberg's, and are developed in order to use Wattenberg's data as support for Strakhov's theory of the dominance of biological processes.

According to Wattenberg, the waters of the Atlantic are supersaturated with respect to $CaCO_3$ in a belt which extends for 60^o on each side of the equator; this supersaturation, according to Wattenberg and Timmermann, is confined to the upper 300 or 400 meters of water. In other words, the surface layers of the oceans and seas (except in the polar regions and the regions traversed by the cold currents) are supersaturated with respect to calcium carbonate. These data show that chemical precipitation of calcium carbonate occurs over virtually the entire area of the oceans and seas from their shores to their central portions.

Strakhov begins to improve on Wattenberg's inferences on page 117: "Only a thin layer of ocean water, confined to the low latitudes, is capable of precipitating calcite chemically." Strakhov develops his conception gradually, and goes on to assert, in the face of a great body of empirical data on Recent sedimentation, that "The only regions where one can expect a significant chemical precipitation of calcite, under present-day conditions, are the shallow near-shore waters of the tropics" (p. 127). Thus, Strakhov bases himself upon Wattenberg's data, and, at first, Wattenberg's inferences, and then goes on to erase, gradually, these inferences, and substitute his own essentially groundless biological and hydrodynamic conception. In a word, Strakhov starts from Wattenberg and, in apparent agreement with the latter, turns a complete somersault.

Strakhov's assertion that the chemical $CaCO_3$ precipitated in the seas is restricted to the spicules (aragonitic, according to Thorp) which entered into pelitic deposits, is also unacceptable. We know, of course, that one and the same mineral will crystallize in different ways under different physical-chemical conditions. This, apparently, is also true of aragonite. In addition, no one has ever demonstrated that $CaCO_3$ must always be precipitated chemically as aragonite, and never as calcite. Finally, $CaCO_3$ spicules are simply never observed in the pelitic limestone deposits of Paleozoic age, which were laid down in shallow, warm seas, and in which chemically precipitated calcium carbonate is doubtless a major component.

The "General Scheme" of Carbonate Deposition in Recent Seas and Lakes

Strakhov attempts to develop a "general scheme" of carbonate deposition for Recent seas and lakes on pages 274-286 of his book. He includes generally accepted data on the distribution of Recent calcium carbonate sediments, but most of these data are presented incorrectly. It is shown that the carbonate sediments are characteristic only of the warm climate belt between 60^o N. Lat. and 60^o S. Lat.; this, however, is only a portion of the earth's surface. Further, the role of the Gulf Stream, and of the vertical circulation in the geosynclinal seas, is ignored. The scheme developed in the section entitled "Distribution of the various processes of carbonate deposition over the surface of the Earth" (p. 275, and Figure 117) is quite elementary; the scheme developed in the section entitled "Zonal distributions of the carbonate minerals over the surface of the Earth" (p. 276 and Figure 118) is simply incorrect. The second scheme is simplified, and the area of siderite distribution is reduced arbitrarily. Strakhov ties the occurrences of siderite on the continents to the northern, tropical, and southern belts of humid climates, and the occurrence of siderite in the ocean only to the northern and southern humid belts. This scheme is incorrect for the following reasons:

(1) Marine siderite is deposited in oceans and seas in all latitudes, if the appropriate physical-chemical conditions are present; (2) continental siderite occurs quite commonly together with other carbonates--dolomite, ankerite, and as an admixture of $FeCO_3$ in calcite deposits--in all climatic zones, and not merely in latitudes higher than 57^o and lower than the belt encompassed by 21^o and 18^o, as is asserted in Strakhov's scheme. The text ignores the widespread occurrence of ankerite in continental deposits, and says nothing at all about calcite deposits with $FeCO_3$.

Strakhov continues to stress the principle that calcium and iron carbonates cannot occur together. In 1948, he wrote, "$FeCO_3$ and $CaCO_3$ are antagonists"; in 1951, he wrote, on one and the same page, (277).

(1) "We are struck by one characteristic feature of continental basins of deposition--the antagonism between the carbonates of iron, on the one hand, and the carbonates of calcium, magnesium, and sodium, on the other"; this assertion runs counter to the widespread

occurrence of ankerite in sediments laid down in land-locked seas and similar continental basins;

(2) On the same page, however, we have the opposite assertion: "An excess of CO_2 can lead to a deposition of iron in siderite or ankerite; the latter, it is possible, is part of a facies richer in carbonates";

(3) "The antagonism between siderite and calcite, and the occurrence of siderite only in facies which are devoid of $CaCO_3$, or which contain a very small amount of this compound.." Here again, siderite and calcite are treated as mutually exclusive.

Thus, at the beginning of page 277, Strakhov stresses the mutual exclusiveness of iron carbonates and the carbonates of calcium, magnesium, and sodium, in general; at the end of the page, he becomes entangled in his own argument, and attempts to restrict the "antagonism" to siderite and ankerite. This is a unique "escape" from a difficult position--the retention of his arguments of 1948, and a simultaneous rejection of these arguments.

Strakhov makes three additional mistakes, however:

(1) He asserts that "... if these conceptions [with respect to continental basins of deposition, especially lakes and swamps - G. T.] are correct, they should be applied, quite obviously [? - G. T.] to marine basins of deposition" (p. 277).

Strakhov's conclusions are incorrect, but even if they were correct for lakes and swamps, they could not be applied to marine, oceanic, lagoonal, or salt lake environments without special investigation of the entirely different physical-chemical conditions which prevail in such basins.

(2) It is asserted on page 276, "The extremely small amounts of magnesium salts in fresh waters force one to doubt that any considerable amount of ankerite could be deposited in the fresh-water lakes of a humid region." Nevertheless, ankerite is not included in a single one of the mineral assemblages shown as diagnostic for the various climatic zones in Figure 118. Lakes, however, may be fresh, brackish, or saline. The occurrence of ancient ankerite deposits is very wide, and does not conform to Strakhov's zonal scheme which, incidentally, he applies to both ancient and recent ankerite. In addition, the carbonates in coal deposits may be represented by ankerite, dolomite, or even calcite, as well as siderite.

(3) We have here, also, a repetition of the erroneous "biolithic" conception of the origin of dolomite in a marine environment: "In the cases in which the sea lies along an arid coast... and rivers do not empty into the sea... carbonate deposits are laid down right up to the shore, and massive accumulations of $MgCO_3$ form in those places in which algae are abundant and the water is warm; diagenetic processes convert these accumulations to dolomite" (p. 278). Thus, all of the various environments in which dolomitic deposits can accumulate in the sea are reduced to the special case of only one environment.

Figure 119 (p. 280) is a diagram which illustrates the relationship between the physical geography of low-salinity seas and the deposition of carbonates; this diagram illustrates Strakhov's thinking, but it is not based on any empirical quantitative data. A chemical precipitation of the carbonate is admitted only for seas in the interiors of continents and for dried-up lakes, but this is immediately followed by a retreat from the position: "In addition, a great part--occasionally a dominant part [this is definitely incorrect--G. T.]--of the carbonate is brought in mechanically, in fragmental form " (p. 281).

The origin of magnesian carbonates, in recent basins of deposition is treated in a manner which is not objective, and is therefore incorrect. We will take up this particular problem below.

Ancient Carbonate Deposition

Only the final portion of the book--72 out of a total of 385 pages--is devoted to this question.

It is rather curious that Strakhov poses only two fundamental problems as he addresses himself to the geologic past at the beginning of this section: "(1) Did all of the known types of carbonate facies exist in the geologic past [All of the known recent types?--G. T.], and if only certain types existed, which types were these? (2) What is the degree of petrographic similarity between ancient and recent carbonate facies of any given type?" (p. 286). Yu. A. Zhemchuzhnikov and others, however, have noted long since that a great number of sedimentary formations and sedimentary economic deposits have been destroyed by erosion. Strakhov, nevertheless, does not even raise the question of formations and facies which have disappeared from the face of the earth. The fact that he ignores this problem entirely is shown on the preceding page, where the relationship between the over-all frameworks of ancient and Recent carbonate deposition is discussed: "Which features of the framework are specifically recent, youthful, and rooted only in the latest stages of a long history of the evolution of the processes of carbonate deposition, and which features ore ancient and

inherited from the past?" (p. 285). Recent carbonate deposition is found to be characterized--upon reading Strakhov's analysis--by all of the fundamental characteristics of both ancient and recent sedimentational processes. Strakhov begins his analysis, in this case, by implicitly overestimating the possiblities of comparative lithology. It is quite another matter, however, when the writer begins to seek, in the ancient carbonates, efficient causes and environmental factors which are unlike anything which characterizes recent carbonate deposition, and unlike any results which are obtained experimentally. Changes in the over-all structure of natural processes constitute one of the primary objects of scientific investigation.

The unchanging nature of the processes of carbonate deposition is asserted again in a later passage: "The over-all characteristics of cross-sections for carbonate facies have remained unchanged at least from the end of Paleozoic time and the beginning of Mesozoic time to the present. It is highly probable, however, that the characteristics of carbonate facies have their origins in more ancient--Precambrian--times" (p. 288). The inconsistency of this assertion, with respect to both the distribution of facies and the mode of occurrence of these facies, is obvious. This, quite simply, is an assertion that the range of types of carbonate facies remains unchanged over geologic time. In 1952, and in his paper before the All-Union Conference on Sedimentary Rocks, however, Strakhov gives a general classification of the authigenous sedimentary deposits laid down from the Devonian through the Recent; the distinction between moist climate and dry climate is the only distinction drawn in this classification. All of the participants in the Conference agreed that Strakhov's approach was invalid.

It is curious that Strakhov's entire argument, in the last analysis, is an attempt to prove the existence of "three classes of carbonate concentrations in water" in the geologic past. These three classes--except for the long-recognized soda class--constitute an entirely artificial classification, elaborated on the basis of secondary characteristics. Virtually all waters in basins of deposition--ancient as well as recent--are grouped together in a single, entirely artificial class which Strakhov calls "the calcium carbonate class."

The analysis of the ancient carbonate rocks of the Russian Platform is carried out, by Strakhov, on arbitrarily chosen specimen material, and without any examination or evaluation of results obtained by other investigators. Strakhov distinguishes three zones in the Carboniferous sea which covered the Russian Platform: the turbidity zone, the silt zone, and the pelitic zone. He also states, however, "The extent of the turbidity zone in the epicontinental portion of the sea was probably enormous, inasmuch as the water was generally shallow and the bottom generally flat"(p. 295). There arises, then, the following question: where were the central portions of the sea in which the pelitic deposits accumulated? Is this not too simple a scheme for the entire Carboniferous of the Russian Platform? We read, on the same page: "The increase in the salinity of the sea occurred in the central portion, and not in the peripheral portions; the latter portions are characterized by symptoms of normal salinity--this is especially true of the Moscow Basin" (p. 295). This is obviously not characteristic of the entire Carboniferous of the Russian Platform. Again, the causes of dolomite deposition are reduced to only the increase in pH which is consequent upon the photosynthetic activity of plants, etc. (p. 296).

We read, in the description of the chalk deposits of the Russian Platform: "This basin was over 2500 km. long, and between 1000 and 1200 km. wide--i.e., practically coextensive with the Carboniferous sea" (p. 299). We know, however, that the longer dimension of the Carboniferous sea on the Russian Platform extended north-south, and the longer dimension of the Cretaceous sea extended east-west. Again, the relief of the bottom of the Carboniferous sea was of an entirely different character from that of the Cretaceous sea. The topographies and the distributions of carbonates in the two seas were entirely different also. Oversight of such facts, however, is not uncommon in Strakhov's book.

The section entitled "Carbonate formations of the southern Urals Foredeep" (pp. 304-313) also contains a number of erroneous assertions, the most important of which are (1) the repetition--in a somewhat modified form--of Strakhov's previously expressed opinion that the Ishimbai reefs are segments of a single enormous reef formation (Strakhov completely ignores the criticisms of this position in the literature) and (2) the assertion that all reef limestones are of exclusively organic origin, with no mention of the existence of chemically precipitated $CaCO_3$ (almost all the reefs in the Ishimbai complex have chemically precipitated incrustations; and scalenohedral calcite crystals--also of entirely chemical origin--are present in some localities). Let us examine Strakhov's first assertion in some detail.

Strakhov follows the views of Gerasimov, Stepanov, and other investigators, in his publications of 1944 and 1947, and. . . . that the Ishimbai reefs are "erosional remnants of a single enormous, formation-like reef of early or middle Artinskian date" (p. 23).

Strakhov continued his defense of the

position in 1951: "The only possibility, apparently, is that these reefs are the erosional remnants of an enormous formation-like reef, and that the erosion occurred in Artinskian time--or, more specifically, in Upper Artinskian time" (p. 311).

Thus, in 1951, Strakhov departs from his argument of 1947 to the extent of identifying the Artinskian relief of the Ishimbai reefs with their present relief; this, obviously, is wrong. In addition, he increases the interval of time over which erosional forces acted--the erosion, now, is "Upper Artinskian" instead of "pre-Upper Artinskian." There is no evidence for such a change in the estimate of the span of geologic time over which erosional forces acted; Strakhov's only motivation in accommodation to the criticism which we leveled against this view. We wrote: "The conclusion that the Ishimbai reef massifs are the erosional remnants of a single, vast reef formation... must be rejected decisively. 'Reef formations' are not observed in nature... In addition, the assumption that several hundred meters of reef massif were removed from the stratigraphic column is highly improbable, because of the very short interval of time--the period of the transition from Lower to Upper Artinskian--which is involved" (1949, p. 155). Strakhov extended the length of time over which erosion occurred only in order to overcome this objection; he designates all of Upper Artinskian time as the interval over which erosion occurred, and identifies the present relief of the reefs with their ancient relief.

We pointed out previously (1942;1947;1949): "The chief factors which controlled the development of the Ishimbai reef massifs were (1) the development (growth and destruction) of the reef colonies themselves, and (2) tectonic movement and erosion after the development of the reefs had terminated, but before burial in the Kungurian evaporites began" (1949, p. 155). We have shown, also (1947;1949), that the history of reefs, in various parts of the Ishimbai area, followed various courses: The development of the reefs of Shikhan (Upper Artinskian) age terminated at the beginning of Irgin time, while the reefs buried in the Kungurian evaporites were above water for a short period between Lower Artinskian (Irgin) and Upper Artinskian (Sargin) time. Consequently, the entire Artinskian history of these reefs cannot be unified into as simple a pattern as that into which Strakhov unifies them by "extending" the time over which erosional processes acted.

Strakhov's treatment of the problem of cratonic and geosynclinal carbonates is contradictory. Thus, he asserts: "We are entirely justified in treating the Carboniferous carbonates of the Russian Platform as the fundamental type of cratonic carbonates" (p. 289). Strakhov also asserts, however, in his discussion of geosynclinal carbonates, that "There are no sharp petrographic distinctions between cratonic and geosynclinal carbonates. There is no doubt, however, that minor differences exist"(pp. 313-314). It is at this point that Strakhov introduces the more-than-doubtful principle by means of which he distinguishes between cratonic and geosynclinal carbonates: "The various limestone facies extend in long, narrow bands which, in general, parallel the various structural units of the geosynclinal region.... It is precisely this unique, structural characteristic of geosynclinal carbonates which necessitates [?--G. T.] a distinction between them and cratonic carbonates, and the treatment of geosynclinal carbonates as an independent category" (p. 314).

Carbonates occur in long, narrow bands on the cratonic slope and in foredeeps, generally in deep water zones; they also occur in the shallow water zones atop submarine uplifts. This has been established firmly for the Upper Paleozoic of the Urals foredeep and the eastern slope of the Russian Platform [45]; other geologists have also drawn this inference.

Strakhov states quite correctly, in his discussion of the best procedures for carrying out a comparison of recent and ancient sediments, that it is necessary to compare lithologically similar sediments which were laid down in analogous stages of sedimentary cycles. Here, however, Strakhov is speaking of transgressions and regressions--i. e., of the twelve great cycles into which he divides the post-Algonkian history of the earth. All the geologic facts taken together, however, point to the conclusion that three cycles of much longer duration--the Caledonian, the Hercynian, and the Alpine--are much more significant. This is a firmly established fact (A. D. Arkhangelsky, 1923; A. N. Mazarovich, 1940; etc); we have confirmed this thesis for the Russian Platform (1947;1950;1951); and A. P. Vinogradov, A. B. Ronov, and B. M. Ratynsky (1952) have confirmed it for the Russian and North American Platforms by geochemical methods. [50].

It is curious that Strakhov himself, in his diagrammatic scheme of the evolution of biogenic carbonate deposition, puts these three cycles on the right side, and the geological time scale on the left side. This scheme (Figure 134, p. 319) possesses a certain interest, but is rather arbitrary, both in its representation of the quantitative contributions by the various groups of limestone-secreting organisms, and (partly) in the manner in which the geologic time scale is presented.

Strakhov carries his simplification of the problem to an extreme; he indicates the photo-

synthetic activity of plants and the expulsion of $MgCO_3$ by organisms in general as the only sources of all of the marine dolomites of the Paleozoic, Mesozoic, and Cenozoic. In other words, the chemically precipitated dolomites of the Precambrian seas were converted into biologically precipitated dolomites in Paleozoic times. This simplified solution of the problem ignores the experimentally established fact that calcareous silts will be enriched with $MgCO_3$ if a stream of warm sea water passes over them slowly. We have shown (1946; 1950) that this process (in its various forms) was the fundamental mode of dolomitization in Paleozoic time.

Strakhov's description of the evolution of calcite deposition, through geologic time, and the distribution of the various genetic types of calcite deposits in recent seas is simple and incorrect. Organic evolution in general, and the evolution of the calcite-secreting organisms, in particular, according to Strakhov, "... suggests a continuous and progressive suppression of chemical processes of calcite deposition by biological processes. An increasing amount of $CaCO_3$ was taken up and precipitated by the living organisms each year, and a progressively decreasing amount was precipitated chemically" (p. 319). This view of the matter ignores the cyclical nature of sedimentation--i. e., the fundamental structure of geologic history--and is, therefore, an incorrect and simplified evolutionistic interpretation.

The interpretation of recent calcite deposition is also simple and incorrect: "It is precisely the biological processes of carbonate deposition that played a dominant role in present-day oceans. This deposition is carried on by the benthos on the continental shelf and by the plankton in the pelagic zone. The contribution of chemical deposition is negligible, and is confined only to shallow, coastal waters in the tropics (e. g., the Bahama banks). Continental seas, embayments, and arid zone lakes are the only bodies of water in which biological deposition is still a subordinate process" (pp. 319-320). This interpretation is an obvious exaggeration of the importance of biological processes.

The evolution of the processes of carbonate deposition in general, in the course of geologic history, is also portrayed in an entirely arbitrary manner (p. 322 and Figure 135). Strakhov describes this process as entirely simple, and forgets about the great cycles which constitute geologic history--specifically, he forgets about the rhythmic unfolding of that history, about the cyclical variation of the CO_2 content of the atmosphere in the course of geologic history, etc. We cannot escape the fact that the decrease in the rate of dolomite deposition, which has occurred since Precambrian times, has had a cyclical structure; this has been demonstrated by A. P. Vinogradov, A. B. Ronov, and B. M. Ratynsky (1952) [51]. Primary chemical dolomite is characteristic of the Precambrian and to some extent the Paleozoic; the Mesozoic dolomites are mainly replacement deposits. We know, of course, that the salinity of the world ocean (i. e., the concentration and composition of the dissolved salts) was altered by run-off from the continents and magmatic extrusions; the concentration of CO_2 in the atmosphere, the relief and climate of the earth, the temperature of the atmosphere--all of these underwent change, and therefore the carbonate balance of the seas and of marine and lagoonal bottom sediments also underwent change. This entire complicated history, with its many thresholds, cannot be reduced, under any circumstances, to merely the influence of algae or the diagenesis of lime-magnesian skeletal remains.

The description of the deposition of dolomite and magnesite in the Kungurian lagoons of the Bashkir region (as we find it in Strakhov's book) is neither objective nor correct. Let us examine this description.

In the section entitled "The fate of lagoonal dolomite deposition in post-Paleozoic times" (pp. 344-345), we find a repetition of the erroneous assertion that all Paleozoic lagoonal dolomites (and occasional Mesozoic and Cenozoic dolomites) were without exceptions, deposited before the deposition of gypsum commenced, and that dolomite could not and cannot be deposited, under any circumstances, once the water is saturated with respect to $CaSO_4$. This assertion runs counter to a host of facts--the widespread development in nature (particularly in Paleozoic rocks) of variegated sulfate-dolomites and dolomite-sulfates, the presence of dolomite in the majority of anhydrite and gypsum deposits, etc. Strakhov raises the question: Did the dolomite stage vanish from Cenozoic and recent lagoonal deposits? We answered this question in a series of papers (1946;1947;1947;1950). What is involved here is the fact that one must consider the chemistry of the lagoonal waters, as well as the stage of geologic history (the amount of CO_2 in the atmosphere, etc.). The precipitation of dolomite in the saline waters of the present-day Aral-Caspian Basin is inhibited, where the concentration of $CaSO_4$ is below the saturation value, by the large $MgSO_4$ and $CaSO_4$ components in the salts. The inhibition of dolomite precipitation in the lagoons of the Black Sea, on the other hand, is much weaker; here the water is of the normal marine type, but the mineralization is one-half that of the ocean. Nevertheless, the carbonate component in the sediments of the Kara-Bogaz-Gol, near the straits, consists of dolomite with admixtures of calcite or magnesite.

Again, one cannot agree with Strakhov's statement that "The concentration of atmospheric carbon dioxide decreased gradually to its present very low value" (p. 344). There is no doubt that this decline was complicated by periodic increases in atmospheric carbon dioxide.

Strakhov attempts to reinforce his position by turning from lithological considerations to considerations of historical geology (also a comparative method). Specifically, he writes: "It is necessary to carry out comparative studies of the entire succession of lagoonal deposits, from early Cambrian times to the present" (p. 345).

Strakhov begins the section entitled,"Regularities of carbonate deposition in the geologic past", with a discussion of the stratigraphic distribution of the carbonates; this distribution is illustrated in Figure 150 (p. 348). Strakhov has published this diagram several times (one might add that there are a number of such diagrams in the book), even though this diagram (like others) is incorrect in many respects, and has been criticized in the literature as a reproduction of Stille's epeirogenetic scheme. Again, Strakhov's Figure 150 is clearly incorrect, inasmuch as it shows the increase in carbonates to accompany an increase in clastics. Strakhov develops his more-than-controversial thinking, I would say his downright incorrect thinking, on page 349, without presenting any concrete examples. "The diagram (Figure 150) attempts to portray these variations in the intensity of limestone and dolomite deposition on the basis of the data obtained in regional geologic studies, chiefly in areas where carbonate formations have undergone considerable development of areal extent and partly [?--G. T.] in point of thickness" (pp. 349-350). Thus, the variations in the mass of deposited carbonates are considered fundamentally from the standpoint of their areal extent and only "partly" (i. e., simply without analysis) from the standpoint of thickness. It follows that the diagram in Figure 150 merely illustrates Strakhov's conclusions; it cannot serve as evidential basis for his argument.

The climate zone distributions of carbonate rocks, during the carbonate epochs, are also quite arbitrary. Thus we read: "Our schematic representation does not necessarily contain points which correspond to all of the known occurrences of limestones, dolomites, or marls in the stratigraphic column, but only those occurrences which we know are characterized by considerable areal extent or [?--G. T.] thickness" (p. 350). Again, we have previously published paleogeographic inferences, rather than actual empirical evidence, in the text. Actually, this section is devoted to an analysis of a distribution of climatic zones which--according to Strakhov--was very similar to the present distribution in Mesozoic and Cenozoic times, and entirely different during the Hercynian cycle; we do not have an analysis of climatic control of the distribution of carbonate deposits. Strakhov repeats his views on the subject, publishes his climatic maps of Europe for the fourth time, and ignores the specific criticisms which have been leveled against his ideas in the published literature.

At the end of the section, Strakhov states a "conclusion" with which every lithologists and geologists is familiar: that carbonate sediments "are deposited in warm climates, and, to a considerable extent, in arid climates" (p. 353). The section closes with the following uniformitarian statement: "This law [which characterizes the post-Algonkian history of the earth-- G. T.] reflects completely the climatic zonal distribution of the carbonates which we observe at the present time" (p. 353).

Strakhov then goes on to develop the old idea that carbonate compounds are "contaminated by" and "dissolved in" clastic materials, and makes the following uniformitarian assertion about the entire post-Algonkian history of the earth: "This is precisely the same mechanism which controls the distribution of marine and lacustrine facies, in any given climatic environment, at the present time" (p. 354).

In the section which is devoted to the forces which initiate the "carbonate epochs" (we understand this term in the sense in which Arkhangelsky used it), Strakhov indicates two possible explanations: (1) "A temporary increase in the rate at which $CaCO_3$ is precipitated from solution" which follows from "L. V. Pustovalov's periodic law of sedimentation"[18]; (2) a decrease in the rate at which "diluting silicate clastic materials are brought into waters where high-carbonate sediments would accumulate otherwise" (p. 355). The second explanation is clearly false uniformitarianism, inasmuch as it assumes a rate of authigenous sedimentation which is constant over the entire geologic history of the earth. Such a position must be rejected without qualification; it contradicts a host of empirical facts (the variation of the salinity of the world ocean, the variation of the amount of CO_2 in the atmosphere, the variation in the climates of the earth, etc.).

Strakhov advances two mutually related objections to the first explanation. He considers that "Pustovalov's hypothesis maintains a silence" (p. 355) on the subject of the variations in atmospheric CO_2--specifically, the increase and decrease in the partial pressure of the CO_2 in the atmosphere consequent upon marine transgressions and regressions. We

are interested in the essence of the problem, however; we can take the general idea of the roughest possible conception of cycles of sedimentation, cycles which are only approximately contemporaneous and not universal, and assert that the partial pressure of the atmospheric CO_2, consequent upon an increase in volcanic activity, is also consequent upon the tectonic movements with which the transgressions and regressions are associated [46]. Indeed, the carbonate ($CaCO_3$) maxima coincide, at least in Europe and North America, with the middle portions of the Caledonian, Hercynian, and Alpine orogenic periods which, in turn, were accompanied by marine transgressions in the cratonic regions. Orogenic movements proper, however, were accompanied by marine regressions, intensified volcanism, and an increase in atmospheric CO_2. The temperature of the atmosphere, throughout the world, was increased because of the additions of carbon dioxide. The transgressions (in the cratonic regions) which occurred in the middle portions of the Paleozoic tectonic cycles gave rise to extensive shallow, warm seas--i. e., created conditions favorable to the deposition of carbonates, and especially calcium carbonate--in a period when the atmosphere of the earth was enriched with CO_2; these climatic conditions were also favorable for the development of a rich continental (mainly swamp) vegetation. The precipitation of carbonates in lagoons is intensified when regression commences; these sediments are predominantly dolomitic (if the partial pressure of the atmospheric CO_2 is sufficiently high). These sediments are frequently covered by the deposits laid down during the last weak returns of the transgressing sea on the craton, and beneath the argillaceous-arenaceous clastics that are brought down into marginal geosynclines from the rising adjacent mountain systems. The energetic development of coastal marsh and inland swamp vegetation, as well as of the marine plankton, leads to the accumulation of the largest coal deposits, and the preservation of carbonates and petroleum hydrocarbons in the marine sediments; the last, of course, are converted to oil deposits if the region has the proper type of subsequent tectonic history. The absorption of CO_2 by plants commences at the beginning of a period of transgression, and continues while the sea covers the craton. This reduces the partial pressure of the atmospheric CO_2 and intensifies the deposition of calcium carbonate. The atmosphere is then enriched with CO_2, and the lagoonal sediments which are laid down at the beginning of a period of marine regression consist of dolomites and salts. Thus, the problems which Strakhov regards as chronic obstacles to the explanation of the mechanism by which "the carbonate epochs of the earth's history" are initiated (if the cyclical nature of that history is ignored) are given a very natural explanation if we take the cyclical nature of that history into account.

The second line of argument, which explains the "carbonate epochs" only in terms of a decrease in the amount of clastic material brought into the sea during periods of marine transgression, is clearly incorrect, inasmuch as the argument necessarily involves the assumptions that the rate of authigenous sedimentation remains constant over all of geologic history, and that only the deposition of clastics is cyclical. It is precisely the chemical precipitates, however, which have the most sharply expressed cyclical character; this cyclical character, of course, is consequent upon changes in relief and climate.

The second line of argument corresponds to the position which Strakhov espoused in his treatment of the problem of chemical differentiation in sediments; Strakhov, on the one hand, is silent about this position and ignores it, but, on the other hand, introduces it under the term, "facies cross-section," especially in his treatment of sedimentary ore deposits. The inconsistency of Strakhov's silence on the subject of chemical differentiation of sediments in space has been noted widely, and is understood by everyone. (In his article of 1952, Strakhov already uses the term "chemical sedimentary differentiation.")

The denial of chemical deposition of carbonates in the course of the earth's history constitutes, simultaneously, a denial of the fact that the waters of the oceans and seas have undergone a chemical evolution, and at the same time a denial of the lack of uniformity in organic evolution, and a denial of variation of the CO_2 content of the atmosphere, etc. These denials are unacceptable. At the same time, however, one cannot ignore the fact that the proportion of terrigenous clastics increases during periods of marine regression and orogeny, and decrease during periods of marine transgression. Consequently, the "carbonate epochs" of geologic history are initiated by simultaneous increases in the chemical precipitation of carbonates and decreases in the amount of "diluting" terrigenous material which is brought into the seas. These are two sides of a single tectonic process. To be sure, all of the processes which we have touched upon are not initiated in a uniform manner over the entire earth; their durations are variable, and the processes are not always initiated in all of the geosynclines.

Strakhov goes on to draw the following erroneous conclusion: "The most favorable environment for the deposition of carbonates always has been that of warm, tropical or subtropical waters, adjacent to arid continental regions" (p. 356). One would think that this conclusion was not applicable to the Precam-

brian, when there was no continental vegetation, and especially to the Archean, when climatic conditions over the entire earth were entirely different and the distribution of carbonates in space was controlled by an entirely different set of factors. But here again we have the repeated statement: "The second of these laws corresponds entirely to what is observed at the present time" (p. 356). We ask, then, where is the correction for the effects of geologic history which, apparently, even Strakhov recognizes?

The last section of the book, entitled "Similarities and differences between recent and ancient processes of carbonate deposition," shows that Strakhov, in the last analysis, continues to defend his old views, and retain his erroneous uniformitarian approach to lithology, in spite of the fact that his approach has been the subject of discussion and criticism for a number of years.

He writes, on page 356: "All of the controlling characteristics of the facies cross-section of carbonates laid down in a normally saline marine environment came into being at an extremely remote time--at the end of the Algonkian, at the latest--and characterize the deposition of carbonates through all of geologic history, down to the present moment. This is why the study of recent sediments, which can be carried out in a most thorough and comprehensive manner, will yield results that are applicable, without serious error, to sediments laid down over all of post-Algonkian time." It is difficult to imagine a more candid testimony to the constancy of sedimentational processes--and this after widespread discussion: Strakhov, apparently, has gained nothing from the discussion; he simply defends his old position.

In various places in his lengthy book, Strakhov continues his defense of the unchanging nature of the environment of sedimentation over all of post-Algonkian time. It should be clear to everyone that Strakhov's "uniformitarianism" constitutes a simple, Huttonian approach which is entirely unacceptable, in spite of the fact that Strakhov's book includes statements of opposing views. Strakhov's reason for postulating constant conditions of deposition for all post-Algonkian time is that "This period is only some five hundred million years long, while the entire history of the earth has extended over three or four billion years" (p. 356). That is to say, the duration of the history of the earth is between six and eight times the duration of the post-Algonkian. The trivial nature of this argument is obvious to every geologist.

The following inference, drawn by Strakhov, is also incorrect: "The specifications of ancient sedimentation, and their development down through geologic time, become obvious only when ancient sediments are compared with recent sediments" (p. 357). The error of this assertion lies in the fact that recent sedimentation is only the last stage of an evolutionary process; it is clear that the evolution of sedimentary processes can be detected along the entire chain quite clearly, even if we ignore recent processes. Fortunately, the statement about the evolution of sedimentary processes remains nothing more than a statement, inasmuch as Strakhov simply reaffirms the unchanging nature of these processes in the "historical" past.

We share the view that comparative lithology is a fruitful and promising line of investigation, and deserves energetic development; it cannot be taken as the basis of the study of ancient sediments, however. Comparative lithology, obviously, should be included among the petrological techniques that are brought to bear on the problem of ancient sedimentation; it is not to be used in the rigidly uniformitarian manner in which Strakhov uses it, however; it is to be adapted to the realities of historical geology.

Strakhov attempts to credit comparative lithology with the achievements of other petrographic and sedimentological disciplines in his final paragraph, and attempts to unify comparative lithology and historical geology.

If we are to believe Strakhov's assertion that "in the light of what comparative lithology tells us about the evolution of sedimentational processes" (p. 357), then "virtually all previous genetic schemes for rocks of chemical and biological origin" (p. 357) become unacceptable by virtue of the fact that they ignore the time factor. We saw, above, however, that Strakhov himself defended the thesis that the structure of the sedimentation cycle for the carbonates remains constant over all of post-Algonkian time (p. 356), and based his defense on 355 pages of comparative lithologic data.

It is impossible, also, to agree with the final sentence of the book, which asserts the repetitive structure of individual cycles of sedimentation, and of the evolution of sedimentation as a whole, and goes on to assert that "a quick and correct solution of this fundamental problem, outside the framework of comparative lithology, is impossible" (p. 357). We pointed out above that the geologic present is merely the last link in a long evolution of sedimentational processes, and that the laws which govern this evolution, generally speaking, can be determined without necessarily referring to recent sediments. Recent sediments, however, should not be neglected. The last sentence in Strakhov's book permits one to infer that he regarded comparative lithology as the only truly basic approach to the evolution of sedi-

mentation, as late as 1951. We have demonstrated, in the course of our discussion, the error of Strakhov's point of departure; this error flies in the face of logic and sound judgment by introducing a theory of the evolution of sedimentation--i. e., the criteria of historical geology and natural history--into the study of present-day phenomena.

The Deposition of Magnesium Carbonates in Recent Basins, with Special Reference to Saline Lagoons

Strakhov distinguishes the following three fundamental classes of dolomites in the present-day oceans and seas: (1) fragmental dolomite; (2) diagenetic dolomite, in the broad sense of the term; (3) diagenetic dolomite precipitated from the waters in bottom silts (p. 127).

The fragmental dolomite comprises a purely theoretical category, inasmuch as entirely pelitic dolomites and dolomitic limestones are not encountered in nature. The distinction between the two types of diagenetic dolomite is also difficult to understand, inasmuch as all such dolomites are deposited in quantities which are governed by the carbonate balance in the bottom silt waters. Thus, Strakhov's classification only indicates the various possible processes by which dolomite may be deposited; these processes have been investigated long ago, however, and this classification does not include all of the known types of dolomite by any means. Strakhov utterly ignores the deposition of diagenetic dolomites in areas in which slow currents move through a shallow sea (experimental data and observations in present-day seas, as well as many examples in the Paleozoic), or in areas of upwelling currents.

Strakhov speaks first of Lake Balkhash (p. 247), and then about salt lakes of the "magnesium carbonate" type (p. 248) in general. He asserts that the deposition of magnesium salts begins when the alkali reserve is equal to or greater than 8 milligrams-equivalent per liter, and the pH is equal to or greater than 8. 8. We have already pointed out that these values are applicable only in the case of a specific type of water--the weakly mineralized sulfate-carbonate water of Lake Balkhash, for example. The application of these alkali reserve and pH values to all of the lake waters of the so-called "magnesium carbonate class"--a class which includes a vast number of lakes on an entirely artificial basis--is unjustified.

Strakhov goes on to set out the utterly untested parameters of magnesium carbonate deposition for his so-called "magnesium carbonate" lakes: "Magnesium carbonate makes its appearance as a dolomite deposit when the salinity attains a value between 0. 4% and 0. 5%, the alkali reserve a value between 8 and 9 milligrams-equivalent, and when the pH value is approximately 8" (p. 253). In a word, calcite-dolomite silt comes into being under these conditions. Similar processes are initiated in the salinity range between 0. 5% and 6% or more, "...but the deposition may cease if the mineralization is between 10% and 12%, and the deposition of a mixture of calcite and basic magnesium salts is initiated" (p. 253). A new hypothesis of the origin of the dolomite in the bottom silts of Lake Balkhash is then advanced: the dolomite appears, at the earliest stages of diagenesis, in the mixture of chemically precipitated calcite and basic salts of magnesium carbonate (this is no longer the primary dolomite of Strakhov's first hypothesis). Here Strakhov attempts an obviously erroneous explanation of why calcite and magnesium carbonate salts are precipitated separately at high mineralizations. Strakhov advances the entirely hypothetical suggestion that magnesium carbonate lake waters with high mineralization may be the scene of "the deposition of excess calcium as $CaSO_4$, which inhibits the deposition of dolomite, a mineral which is never found in such deposits" (pp. 255-256); "the magnesium salts are neutralized during diagenesis, and form dolomite in lake waters with low or medium salinity, however" (p. 255).

O. K. Yanatieva, at the Institute of Inorganic and General Chemistry (IONKh) of the Academy of Science of the USSR, demonstrated in 1941 that an increase in the $MgSO_4$ concentration will reduce the chemical stability of dolomite in waters with high mineralization. Dolomite becomes extremely unstable when the $MgSO_4$ concentration becomes rather high, and decomposes into $MgCO_3$ and $CaSO_4$. This occurs at various mineralizations in waters of various types. We have utilized Yanatieva's results in our publications (1942; 1946). In 1949, Yanatieva published her solubility and stability diagram for dolomite in the system (Ca, Mg) CO_3-SO_4-H_2O; she published a more detailed report on her investigations in 1950.

Strakhov completely ignores all the publications; instead, he proposes--without resort to any experimental data--that "the appearance of $CaSO_4$ in the sediment may well constitute the stimulus which causes the deposition of dolomite to cease (p. 255). He attempts to argue theoretically that the saturation of a solution with respect to $CaSO_4$ inhibits the precipitation of dolomite in "calcium carbonate" waters as well as in "magnesium carbonate" waters. Strakhov has repeated the same "theoretical argument" over a number of years (1945; 1947; 1951) [25, 27, 29] this argument purports to explain the inhibiting roles of $CaSO_4$ with respect to dolomite, and consequently the separate precipitation of $CaCO_3$ and magnesium carbonate salts in waters

with high mineralization. According to Strakhov, the reason for this inhibition is "quite possibly, an unfavorable calcium balance. The calcium is divided between the $CaCO_3$ and the $CaSO_4$ in the embayments of the Caspian Sea, where the salinity is greater than 6%. The water is saturated or even, to some extent, supersaturated with respect to these salts. Any additional calcium which is introduced into the bottom silt water is immediately divided between the $CaCO_3$ and the $CaSO_4$, supersaturates these salts, and is precipitated as calcite or gypsum. Inasmuch as the solubility of dolomite, apparently, is greater [?--G. T.] than that of calcite, it is precisely an excess of calcium over the previous saturation value that is required for a saturation of the bottom silt water with respect to dolomites. The physical impossibility of such an excess arising in an environment in which the silt water is saturated with respect to $CaCO_3$ and $CaSO_4$ (and any excess calcium is immediately dispatched down one of two channels) constitutes the reason why the silt waters in the lagoons of the Caspian are chronically undersaturated with respect to dolomite, and no dolomite is precipitated. In other words, Heidinger's reaction, which produces magnesite in sediments with high salinity, also initiates the precipitation of dolomite. This is a magnesite-producing reaction, and not a dolomite-producing reaction" (p. 273).

Strakhov's reasoning from physical chemistry--i. e., on theoretical grounds--is without foundation; it is contradicted, actually, by the widespread occurrence of sulfate-dolomite and dolomite-sulfate deposits (the "gypsum-dolomite" and "anhydrite-dolomite" of many authors); sulfate-marls and dolomitic anhydrite are also quite common. All these rocks are known from various systems of the Paleozoic, but their distribution is somewhat different from that of the primary chemical dolomites which are characteristic of the pre-Mesozoic systems.

Let us, nevertheless, consider Strakhov's "theoretical analysis." We point out, first, that Strakhov applied this explanation to all types of waters, in all geological ages, in 1945 and 1947; at that time, he did not emphasize "silt waters," as he did in 1951.

1. Strakhov asserts that "the solubility of dolomite, apparently, is greater than the solubility of calcite." We know, however, that solubility depends upon the physical-chemical conditions of the aqueous environment. Various saline systems, under various conditions of mineralization and temperature, at various partial pressures of carbon dioxide in the atmosphere (or in the silt), will behave differently; the solubility of any two minerals can vary in a parallel manner, approach a common value asymptotically, or vary in opposite directions. It is especially necessary to bear this in mind, when we consider a case in which the solubilities of two double salts approach a common value (van't Hoff: Lectures on the synthesis and decomposition of double salts, Russian translation, 1937); this is precisely the system in which dolomite is precipitated at a CO_2 partial pressure of 1 atmosphere. Here the solubility of the double salt is lower than the sum of the solubilities of its constituents--i. e., the solubility of each constituent is greater than the fraction of the solubility of the compound which corresponds to the constituent's contribution to the total molecular weight. Thus, no excess of $CaCO_3$ is required for the precipitation of dolomite. Further, Yanatieva has shown that "the solubility of dolomite is always less than either the solubility of calcite or the solubility of magnesite" in the specific case of the system $(CaMg)CO_3$-SO_4-H_2O when the partial pressure of the CO_2 is 1 atmosphere, the temperature is 25°, the concentration of magnesium sulfate is comparatively low, and NaCl is present. [52]

2. The presence of $CaSO_4$ in a solution decreases the solubility of $CaCO_3$, but the other salts of sea water--NaCl, $MgSO_4$, or $MgCl_2$, for example--increase the solubility of calcite over wide mineralization ranges. Thus, the reduction of the solubility of $CaCO_3$ consequent upon saturation of the solution with respect to $CaSO_4$ can not be very significant; actually, the solubility of calcium carbonate begins to increase when normally saline sea water is evaporated to the point where it becomes saturated with respect to NaCl.

3. The organic matter in the bottom silt water--which is saturated with respect to $CaCO_3$ and $CaSO_4$--gives up CO_2. In these conditions, any additional calcium which is introduced into the water can combine with the free carbon dioxide to form $Ca(HCO_3)_2$. Any additional calcium that is introduced into the bottom sediments, then, will be precipitated, but it will be precipitated as $CaSO_4$, not as $CaCO_3$. If we bear in mind what we have said previously about the solubilities of double salts and their components, we can see that the first carbonate to be precipitated will be dolomite and not magnesite or calcite, especially in bottom sediments with normal marine salinity.

4. In his book, further, Strakhov applies his reasoning to the waters of the Caspian Basin; these waters are distinguished by high $MgSO_4$ and $CaSO_4$ concentration. They become saturated with respect to $CaSO_4$ earlier than the waters in lagoons with normal marine salinity; and any dolomite which is precipitated is extremely unstable, because of the high magnesium sulfate concentration. An examination of the general question of the sequence of

carbonate salt precipitation on the basis of the data for the waters of the Aral-Caspian Basin only, involves one in considerable difficulties; these waters have been studied some time ago by Ilinsky, Klebanov, and Bader and Teodorovich, and were found to belong to only one of a number of types of waters with chemistries that differ from the normal marine [7, 46].

5. Strakhov speaks, also, of the aqueous solution in the bottom sediments, and the necessity of an excess of Ca ions for the initiation of dolomite deposition; he assumes either a supply of this excess via ground water (highly improbable for lagoons and lakes with high salinity), or reactions in the silts. We know, however, that sulfate-dolomites are precipitated as particles from the water which overlies the silts, in lagoons with normal marine salinity, and not in the silts themselves. The sea water which continually flows into a lagoon contains more calcium carbonate than magnesium carbonate. The lagoon is converted into a coastal salt lake if the connection with the sea is cut; this connection, obviously, can be re-established. A shortage of $CaCO_3$ in lagoonal waters, therefore, is impossible. Further, an excess of calcium ions is not required, inasmuch as (generally speaking) it is an excess of magnesium ions that is required for the precipitation of dolomite in seas and lagoons. More specifically, a considerable concentration of $MgCO_3$ is required; this is observed in high-salinity lagoons which are fed by waters from normally saline seas (until the water is saturated with respect to NaCl, or nearly saturated with respect to $MgCO_3$).

6. It is simply untrue that the addition of excess calcium ions to a solution saturated with respect to $CaCO_3$ or $CaSO_4$ will entail the precipitation of these salts. This contradicts what we have indicated above concerning the solubilities of dolomite and calcium carbonate, inasmuch as it is based on the assumption that the solubility of dolomite will always be greater than the solubility of calcite; Yanatieva has shown that the solubility of dolomite is substantially less than that of calcite when the partial pressure of the CO_2 is 1 atmosphere. Any excess $CaSO_4$, however, will be precipitated directly. The precipitation of $CaSO_4$ in a solution saturated with respect to this salt will entail a reaction between the $CaCO_3$ and the $MgSO_4$, and, in the end, the precipitation of dolomite or hydromagnesite (depending upon the concentration of $MgSO_4$).

7. Heidinger's reaction is treated erroneously, and the reason for the replacement of a calcite-dolomite sequence by a calcite-magnesite sequence, in an environment with increased mineralization, is also indicated incorrectly: "In other words, Heidinger's reaction is initiated in bottom sediments which contain a considerable amount of magnesite.... It is not a reaction which deposits dolomite, but a reaction which deposits magnesite"(p. 273). We have shown previously, however, that saturation of the solution with respect to $CaSO_4$ does not hinder the precipitation of dolomite. The common occurrence of sulfate-dolomites in nature (as well as dolomite-sulfates), and the fact that the majority of gypsums and anhydrites are dolomitized, is a clear-cut evidential refutation of Strakhov's argument. On the other hand, Strakhov speaks of the appearance of magnesite "in the bottom sediments" of lagoons. This is inexact, since the magnesium oxide particles come into being in the water above the sediments, and are only neutralized in the sediments.

Strakhov develops his "discussion and explanation" without any regard for the earlier experimental data on reactions involving $MgSO_4$ in aqueous solution (Kurnakov's and Heidinger's reactions), or the reasons for the replacement of dolomite by magnesite at increased mineralizations. As far back as 1942, we utilized Yanatieva's experimental results and a body of petrographic data to show that the production of (primary and diagenetic) dolomites continues in lagoonal and marine waters until those waters become saturated with respect to NaCl. We wrote, in 1946: "If the solution is saturated (or nearly saturated) with respect to $CaSO_4$, we have, first, a complete dolomitization of the calcareous bottom silts, and then a precipitation of fine-grain primary dolomite, as waters with dissolved calcium carbonate continue to enter the lagoon.... Actually, we have a precipitation of primary dolomite-sulfates." Yanatieva, of course, has shown that dolomite becomes unstable as the concentration of $MgSO_4$ increases; this is to be observed in the Kungurian lagoonal deposits. We have been able to establish, on the basis of lithological data, that "$MgCO_3$ is precipitated as magnesite (or hydromagnesite) when the lagoonal water begins to approach saturation with respect to NaCl, because of evaporation; magnesite and calcium carbonate will be precipitated simultaneously if waters with dissolved $CaCO_3$ continue to enter the lagoon" (1946, p. 827).

Thus, we knew in 1946, from lithological evidence considered in the light of physical-chemical experimental results, the overall nature of the conditions under which dolomite and magnesite are deposited in high-salinity lagoons. We examined the boundary conditions for, and the courses taken by the various reactions which involve $MgSO_4$; we showed that if the concentration of NaCl is less than the saturation value, the reaction with which we are concerned here occurs in two stages:

(1) $CaCO_3 + MgSO_4 \rightarrow CaCO_3 + MgCO_3$ (in

solution);

(2) $CaCO_3 + MgCO_3 \rightarrow CaCO_3 \cdot MgCO_3$.

The first reaction--which involves $MgSO_4$--is a dolomite-precipitating reaction in lagoons in which the NaCl concentration approaches the saturation point (we speak here, of course, of unaltered, evaporated sea water.)

Yanatieva's experimental results showed, further, that the dolomite becomes unstable and decomposes to form magnesite and $CaSO_4$ in evaporating lagoonal or marine waters in which the $MgSO_4$ concentration is high. Lithological studies of the Paleozoic of the European USSR have shown that $MgCO_3$ was precipitated as magnesite, or the precipitation of calcite and magnesite was initiated when the NaCl concentration in these ancient waters approached the saturation point, and fresh sea water with a large amount of calcium carbonate in solution was fed into the lagoons. One should note that in some cases, when the lagoonal waters were "metamorphosed," and the concentration of $MgSO_4$ was extremely small or even zero, rock salts and other readily soluble salts can contain dolomite (which, apparently, is produced in reactions which involve $MgCl_2$) as their main carbonate component; the percentage of dolomite, in these cases, however, is very small.

The increase of the partial pressure of the atmospheric carbon dioxide, which occurred in Precambrian and Paleozoic times, expanded the portion of the earth's surface over which stable dolomite could be deposited; at the present time, this portion is considerably smaller.

8. Strakhov writes: "Even though we do not know the solubility of dolomite as yet [?--G. T.], we can assume that it lies somewhere in the interval between the solubilities of calcite and magnesite" (p. 255). He asserts further, however, that "in former times, the saturations of $CaCO_3$ and $MgCO_3$ in the waters of the Kara-Bogaz-Gol were different, and therefore these salts were deposited in different amounts. The deposition of dolomite did not occur" (p. 70). These two statements contradict each other (we pass over the fact that the first statement is completely wrong). We have shown, actually that dolomite is unstable in the waters of the Kara-Bogaz-Gol, because of the high $MgSO_4$ concentration [46]. Only the first stage of the reaction we indicated above, $MgSO_4$:$CaCO_3 + MgSO_4 + 2H_2O \rightarrow MgCO_3 + CaSO_4 \cdot 2H_2O$, occurs; the second stage of the reaction ($CaCO_3 + MgCO_3 \rightarrow CaCO_3 \cdot MgCO_3$) is impossible in this environment. Thus, dolomite is not deposited in highly saline waters, such as those of the Kara-Bogaz-Gol, inasmuch as the chemistry of the water prevents the synthesis of new dolomite and the survival of preexisting dolomite. This explains the absence of dolomite from the bottom sediments of the Kara-Bogaz-Gol.

The Production of Magnesium Carbonates in Ancient High-Salinity Lagoons

It is utterly impossible to accept Strakhov's assertion that "Two types of carbonate minerals are to be found in the Kungurian salt deposits: (1) large beds made up of limestones and dolomites, and (2) more or less substantial admixtures in anhydrites, halites, clays, marls, and sandstones" (p. 327). We ask: why is the third (actually, the second most important) type of magnesium carbonate excluded? This type includes the primary sulfate-dolomites and dolomite-sulfates. Strakhov's omission of this type of dolomite is not accidental; these deposits bear witness to the deposition, in lower Permian time, of primary chemical dolomite in an environment which was saturated with respect to $CaSO_4$; Strakhov, however, devoted several publications to the denial of this indisputable and frequently demonstrated fact of nature, and submitted a "proof" of the impossibility of the precipitation of dolomite in solutions saturated with respect to $CaSO_4$ (we will say nothing here about the precipitation of dolomite with the aid of $MgCl_2$ in chemically altered lagoonal waters).

The common occurrence of limestones, dolomites, dolomite-anhydrites, and dolomite-gypsums in rocks of Lower and Upper Permian age (these deposits are lagoonal) makes it impossible to accept the following assertion by Strakhov: "The deposition of carbonates in lagoons is a very minor occurrence" (p. 328). This conclusion is justified only for lagoons in which the salinity is so high that NaCl and various salts of magnesium and potassium are precipitated; this also explains the very rapid rate at which these salts are deposited. Strakhov considered, from 1945 to 1951, that the saturation of lagoonal waters with respect to $CaSO_4$ excludes the precipitation of dolomite. We showed in 1946, however, that primary dolomite-anhydrite and anhydrite with dolomite components were deposited in lagoons saturated with respect to precisely this salt; the carbonates, in such waters, are represented by magnesite, or magnesite and calcite, in the event that the water is saturated with respect to NaCl [43].

One cannot ignore the obvious and by no means accidental contradictions in Strakhov's picture of the distribution of magnesite in the Kungurian of Bashkir. Thus, we read, first: "In the halites, and in all other rocks in which NaCl is dominant, the carbonates occur as traces or negligible admixtures. . . . But in some cases the carbonate component rises to

1% or more, and can be detected by thermal or optical methods. Thus, for example, of 18 salt samples for which thermal analyses were carried out, only 10 samples give clear-cut indications of the presence of carbonates. The carbonates in these samples were also detected by other methods. Microscope examination of powdered salt samples made it possible to establish the presence of carbonates in 9 instances. In all cases, the chief carbonate mineral was magnesite" (p. 332). The conclusion which is then given, however, contradicts the data: "Magnesite, on the other hand, is a stratigraphically localized mineral and is associated, in the main, with the gypsum-anhydrite horizon. This mineral was observed in only 4 of 100 samples from the salt horizon, but it was observed in 30 of 104 samples from the gypsum-anhydrite horizon. The difference is sufficiently obvious" (p. 335). This conclusion confuses the reader.

Actually, the rapid deposition of NaCl which characterizes the accumulation of halite deposits suppresses and masks the deposition of all carbonates, and especially magnesite. It is precisely this circumstance (which Strakhov himself notes on page 333) which explains the fact that magnesite (or, for that matter, carbonates in general) is detected in only 4 of 100 salt samples, even though it is doubtless present in very small amounts in all halite samples. Thus, magnesite is the dominant carbonate in the salt horizon. On the other hand, magnesite is the dominant carbonate in 30 of 104--i. e. ,in 27% ---of the gypsum-anhydrite samples. The presence of magnesite in approximately 25% of a run of such samples is explained easily. We have already noted that "the precipitation of $MgCO_3$ in the form of magnesite, alone or together with $CaCO_3$, begins when the concentration of NaCl in a solution approaches the saturation point"[43]. In other words, we have demonstrated that magnesite can be the dominant carbonate in a number of sulfate deposits (anhydrite, or, more rarely, gypsum or other minerals).

Strakhov gives a brief survey of the results of chemical analysis of the Kungurian in the Tuimaza, Chusovo, and Solikamsk districts. The absence of magnesite in the dolomites, dolomitic limestones, and calcite limestones is noted. Dolomite is found to be the dominant carbonate in 28 out of 34 anhydrite and gypsum samples (that is, dolomite accounts for between 80% and 100% of the total carbonates); magnesite was detected in only 2 anhydrite samples (from Chusovo), and it comprised 2. 21% and 1. 6% of these samples. It is stated here: "The characteristic feature of these salt deposits is the widespread occurrence of magnesite, and the predominance of this mineral over dolomite and calcite" (p. 337). All of the data support the explanation of the occurrence of magnesite in high-salinity lagoonal deposits which we advanced in 1946.

The third part of Strakhov's book contains a section (in Chapter II) entitled "A genetic classification of the lagoonal sediments of the Kungurian in Bashkir"; this section contradicts a host of empirical data, and calls for many objections, in spite of the fact that it is only three pages long (pp. 341-344). The section begins with a "reminder" (the assertion had never been made before) that the sea and lagoons of Permian time, in this region, belonged to the "calcium carbonate class" of waters, to which (according to Strakhov) all of the recent and ancient seas, lagoons, and many lakes (back through all of Paleozoic time) belonged. Strakhov also asserts, however, that "the deposition of carbonates in these lagoons proceeded in a manner entirely distinct from that in which carbonate deposits are laid down in present-day lagoons" (p. 341). This all-too-dogmatic assertion, however, is based upon a comparison of Permian lagoonal deposits with normal marine salinity, on the one hand, and the recent lagoonal deposits of the Aral-Caspian Basin, on the other; the deposition of magnesite and basic magnesian salts begins at considerably lower salinities in these waters--when the concentrations of $MgSO_4$ and $CaSO_4$ are high--inasmuch as dolomite becomes unstable very quickly in such as environment, and therefore ceases to appear much earlier.

Strakhov analyzes the lagoonal waters of the Black Sea Basin--the waters of this basin are of the normal marine type--in a very superficial manner, and does not touch upon the carbonates in the bottom sediments. (It should be noted that the salinity of open water, in the Black Sea, is approximately half the salinity of ocean water.) The processes of sedimentation in the Black Sea lagoons, therefore, will differ from the processes in the Permian lagoons, because the partial pressure of CO_2 was greater in Permian times (and the atmospheric temperature was warmer); the difference between deposition in the Black Sea and deposition in the Permian sea, however, will be less than the difference between deposition in the former and deposition in the lagoons of the Aral-Caspian Basin.

It is Strakhov's opinion that "the sudden and early appearance of dolomite is the distinguishing characteristic of ancient lagoonal deposits; dolomite made its appearance in these deposits before the deposition of gypsum was initiated. Subsequently--at high salinities--the deposition of dolomite gives way to the deposition of calcite and magnesite" (p. 341). This entire line of inference is logically contradictory; more important, however, it contradicts a whole array of universally acknowledged empirical

facts. The inference that pure dolomite is deposited before gypsum or anhydrite is, on the one hand, tautological (it is obvious that pure dolomite will be precipitated before $CaSO_4$), and on the other hand, dolomites of various origins are lumped together indiscriminately. Finally, Strakhov is guilty of simply playing with words here. He notes, first, "the deposition of dolomite before the deposition of gypsum," and then he speaks of "the deposition of dolomite giving way to the deposition of calcite and magnesite." If this is true, however, we must ask: Where did the abundant lagoonal primary sulfate-dolomites, dolomites, and anhydrites of Permian age disappear to? Strakhov's categories stretch like rubber: "Subsequently, at high salinities... the deposition of dolomite gives way..." --this is an attempt to cover up the error of his fundamental position by invoking the facts of nature; namely, the presence of abundant sulfate-dolomites, anhydrites, and various combinations of anhydrite (or gypsum) and chemical dolomite in which dolomite is the chief carbonate. The facts bear witness that magnesite is the chief carbonate component from the moment at which the deposition of rock salt commences--more precisely, in sulfates which are precipitated just before the solution becomes saturated with respect to NaCl. On the other hand, dolomite is the main carbonate in halites, which are deposited in lagoons with chemically altered waters from which $MgSO_4$ is absent.

Thus, Strakhov attempts to use facts to cover up an erroneous, rejected, and contradictory hypothesis. Facts, however, are "stubborn things."

It is curious that Strakhov attempts to "prove theoretically," in the third part of his book, that his purely imaginary conception of the influence of $CaSO_4$ concentration on the rate of dolomite deposition is applicable to ancient basins. This attempt explains the following strange statements: "The precipitation of calcium from brine via the deposition of gypsum leads to a situation characterized by the fact that the brine contains a concentration of Ca^{++} such that a saturation of the brine with respect to $CaSO_4.2H_2O$ and $CaCO_3$ is insured. Any excess of calcium ion that may be added cannot remain in the brine very long, inasmuch as it will be 'removed' either by the precipitation of new gypsum, or the precipitation of crystalline $CaCO_3$, or the precipitation of both these substances. The saturation of the water with respect to dolomite by virtue of the fact that its solubility is greater [?--G. T.] than that of calcite, requires precisely that the concentration of the calcium ions be greater [?--G. T.] than that which is associated with saturation in respect to $CaCO_3+CaSO_4 \cdot 2H_2O$. The physical impossibility of obtaining such a saturation after the precipitation of gypsum has begun [?--G. T.] constitutes the reason for the transition from dolomite deposition to calcite-magnesite deposition" (p. 342).

The inconsistency of Strakhov's reasoning is obvious, inasmuch as all of the dolomite in the ancient lagoons would be precipitated before the waters were saturated with respect to gypsum and anhydrite, if Strakhov were correct, and gypsum-magnesite or gypsum-magnesite-calcite facies would make their appearance with the primary sulfate-carbonates. We simply do not observe this in the sulfate-carbonates of the Paleozoic, for example, and, what is more, such a sequence of sediments has not been observed anywhere. On the other hand, there are many instances in which upper Paleozoic sulfate-carbonates overlie rocks that are virtually pure dolomite. Finally, most anhydrites and gypsums contain dolomite as the main carbonate component.

Free $MgCO_3$ is the first carbonate precipitated in an evaporating solution with a high concentration of $MgSO_4$ and $CaSO_4$--as in the waters of the present Aral-Caspian Basin--inasmuch as dolomite decomposes in solutions which contain a considerable amount of the former sulfate. Nevertheless, dolomite has accumulated near the strait through which sea water enters the Kara-Bogaz-Gol (V. D. Poliakov). The dolomite is found in pure form, or mixed with calcite, near the strait; the calcite is replaced by gypsum with increasing distance from the strait, and is replaced by the area of calcite-hydromagnesite-gypsum sediments at even greater distances; these sediments cover most of the embayment. These facts demonstrate the inconsistency of Strakhov's point of department yet again.

Let us, nevertheless, consider the "theoretical" explanation which Strakhov offers as a basis for his entirely imaginative approach to the inhibition of dolomite deposition by $CaSO_4$. We touched upon this "explanation" previously, when we discussed sedimentation in Recent basins; therefore, we will restrict ourselves to indicating Strakhov's fundamental theoretical error. His assertion that the saturation of water with respect to dolomite requires that "the concentration of calcium ions be higher than the concentration associated with saturation with respect to $CaCO_3+CaSO_4 \cdot 2H_2O$" (p. 342) reflects only the fuzziness of Strakhov's thinking about saturation values in solutions of double salts, and the solubilities of the components of such salts. We know, of course, that dolomite is an instance of the second case of a double salt (van't Hoff: Lectures on the Synthesis and Decomposition of Double Salts, Russian translation, 1937; pp. 17-18), in which the saturation of the solution occurs at a concentration of the double salt which is lower than the sum of the saturation concentration

of its constituents. Further, Yanatieva demonstrated that the solubility of dolomite is less than the solubility of either magnesite or calcite if the partial pressure of the CO_2 is of the order of 1 atmosphere [52].

Thus, the saturation of a solution with respect to dolomite requires a concentration of calcium ions which is lower than that associated with saturation with respect to calcite. The presence of $CaSO_4 . 2H_2O$--i. e., the presence of a salt with an analogous ion--will reduce the solubility of the $CaCO_3$, while the dominant salts of lagoonal water ($NaCl$, $MgCl_2$, $MgSO_4$) will increase the solubility of $CaCO_3$; $MgCl_2$ and $MgSO_4$ reduce the solubility of $MgCO_3$. Therefore, Strakhov's assertion that "the physical impossibility" of obtaining a calcium ion concentration necessary for the precipitation of dolomite, once the deposition of gypsum begins and the deposition of dolomite gives way to the deposition of calcite and magnesite, has no basis in fact. The "theoretical explanation" advanced by Strakhov, then, is based on incomplete examination of the elementary data on the solubility of double salts and the corresponding single salts.

In a word, Strakhov's "explanation" is utterly unacceptable, under the aspect of theoretical and empirical considerations alike, inasmuch as it is entirely imaginary, and contradicts a host of firmly established facts of field and laboratory observation.

The erroneous line of analysis adopted by Strakhov leads him to the entirely artificial inference of a principle of "delay" in the initiation of dolomite precipitation, i. e., delay with respect to the moment at which the deposition of $CaSO_4$ commences. Strakhov continues to maintain a silence about the fact that there exists in nature a host of dolomite-anhydrites and similar rocks, but he is forced to admit, nevertheless, that dolomite is the dominant carbonate in anhydrite and gypsum (the admixture of calcite or magnesite is inevitably very small or entirely absent), and that the carbonates are not represented by a mixture of calcite and magnesite, as required by his purely imaginary theory.

The scheme which we proposed (1946), however, does not involve any delay in the initiation of dolomite deposition; there can only be local variations due to the action of extraneous factors. The dominant factor in the deposition of carbonates in ancient high-salinity lagoons is the steady increase in the salinity of the water. The dolomite component in the sediments is replaced by a calcite-magnesite component as the concentration of NaCl approaches the saturation value in normal marine water. The various deviations from this pattern, e. g., the presence of dolomite in some halites, is explained by chemical changes in the water which involve the reduction of the $MgSO_4$ concentration to zero.

The data which Strakhov presents in his book confirm our conclusions fully; more specifically, they confirm the inferences which we drew from our petrographic studies of the upper Paleozoic, and from Yanatieva's physical-chemical investigations. Thus, Strakhov regards magnesite as the dominant carbonate in halites and potassium salts (p. 332), dolomite as the dominant carbonate in pure anhydrites (p. 331) and, again, dolomite as the dominant carbonate in the anhydrite carbonates (p. 332).

Let us now consider Strakhov's "theoretical" explanation of the delay in the initiation of carbonate precipitation (note again, that our hypothesis does not involve any delay). Strakhov begins his analysis at a remote point: "The reason... should be sought in the hydrological properties of all basins which are occupied by highly mineralized brines, and not in carbonate equilibria as such" (p. 342). This sentence is an unsuccessful attempt to make it appear that Strakhov takes the hydrology of highly mineralized brines into consideration; the trouble is that Strakhov ignores the most important factor--the evolution of the composition of the solute, and the classification of bodies of water with respect to carbonates, which occur in very small amounts in brines.

In the absence of any experimental or field data, Strakhov falls back upon the seasonal variation in the temperature and the influx of water, and makes two arbitrary assumptions:

1. Dolomite is deposited at the beginning of the summer, "after which, when the deposition of gypsum commences, the deposition of primary dolomite ceases, and is succeeded by a simultaneous deposition of $CaCO_3$ and $MgCO_3$. The annual balance of sediments will contain a small component in which a certain amount of spring dolomite is succeeded by summer calcite and magnesite" (p. 343).

2. When the sulfates begin to dominate the chemistry of the lagoon, "the spring dilution of the lagoonal brines is very great, and the period of time over which summer evaporation increases the concentration of the solution to the point at which the deposition of gypsum begins is also very great; consequently, the sediment will contain a large amount of dolomite and a small amount of summer calcite and magnesite. The calcite and magnesite components [?--G. T.] may be so small that they cannot be detected by thermal or optical methods" (p. 343).

This explanation awakens doubts, to say the least. To begin with, seasonal variations

seem to give rise to mixed micro-layers; these consist of dolomite which is precipitated first, and calcite and magnesite which are precipitated later, when the solution becomes saturated with respect to $CaSO_4$. Secondly, it is assumed that the summer calcite and magnesite which are deposited instead of dolomite when the $CaSO_4$ concentration becomes sufficiently high are, for some reason, precipitated in a manner such that the sediment contains these carbonates in amounts too small for detection by thermal or optical methods.

Thus, we have two assumptions standing side by side and formulated in a manner which makes verification difficult if not impossible. It is assumed, first, that undetectable variations occur in the composition of the sediment--i.e., there are no empirical data with which the assumption can be tested. On the other hand, the widespread occurrence of primary sulfate-dolomites and anhydrites in nature is a fact which contradicts all these assumptions.

The discussion is concluded with an additional hypothesis, according to which "at very high salinities, which dominate lagoonal chemistry during the precipitation of chlorides, the spring dilution may be such that the brine will remain saturated with respect to $CaSO_4$. Dolomite vanishes from the composition of the precipitated sediments altogether, at this time, and typical calcite-magnesite deposits make their appearance" (p. 343).

Strakhov's reasoning, then, terminates in a third hypothesis which, again, is not substantiated by evidence, and which contradicts the fact of widespread occurrence of primary dolomitic sulfates in the upper Paleozoic, as well as that of the widespread occurrence of dolomitized anhydrites and gypsums; the hypothesis also contradicts the theory of double salts and the data on the solubility of dolomite. Further, data on present-day sedimentation contradicts this conception, and points to the conclusion that seasonal variations are not as important as the space variation of salinity within the individual lagoon. Dolomite and gypsum, with an admixture of $CaCO_3$, were deposited adjacent to Kara-Bogaz-Gol Strait when $MgCO_3$ and $CaCO_3$, together with $CaSO_4$, were deposited over the greater part of Kara-Bogaz-Gol lagoon, and only carbonates, dolomite alone, or dolomite and calcite, were deposited in the areas immediately adjacent to the strait.

Strakhov closes the section with a characteristic pronouncement:

1. He has apparently elucidated "the contradictions, irreconcilable at first glance, between what is required by physical chemistry, and what is observed in lagoonal facies. Actually, everything proceeds according to the laws of physical chemistry, but the precipitates laid down at various stages of the sedimentation process are mixed in nature" (p. 348). We have seen, however, that Strakhov simply does not present any evidence to support his hypothesis of carbonate deposition, and explains this hypothesis by a series of entirely arbitrary assumptions; our hypothesis, on the other hand, is fully supported by the facts.

2. Strakhov tells the reader: "A mechanistic application of experimental data to nature, without considering the specific characteristics of sedimentational processes in nature, can lead frequently to an apparent contradiction between the principles of physical chemistry and the facts of sedimentation" (p. 343). It is precisely Strakhov himself, however, who has recently been guilty of a mechanistic application of the data of Recent sedimentation to the whole of the Paleozoic, and not merely to the Mesozoic and early Cenozoic (p. 365). The contradiction between the physical chemistry of carbonate deposition and the processes of nature, which Strakhov postulates, is not an apparent contradiction, inasmuch as all of the arguments with which he defends his hypothesis are simply invalid.

Strakhov is forced to assume delay effects in natural processes--specifically, in the onset of carbonate deposition in high-salinity lagoons--because his entire frame of reference is distorted; he must also advance a whole series of assumptions in order to explain this "delay." All of these artificial constructions and assumptions are consequent upon the fact that Strakhov's conception of the genesis of dolomite and magnesite in high-salinity lagoons contradicts the facts of nature, it contradicts geologic data for ancient and recent deposits as well as experimental data, and it does not reflect reality.

REFERENCES

[1] Belyankin, D. S., Lapin, V. V., and I. A. Ostvovsky., THIN SECTION AND POLISHED SURFACE STUDIES OF DOLOMITIZED LIMESTONES. [ISSLEDOVANYE DOLOMITIZIROVANNYKH IZVESTNYAKOV V ANSHLIFAKH V OTRAZHENNOM SVETE]. Izvestia Akademii Nauk SSR: Seria Geologicheskaya, 1940. No. 2.

[2] Berg, L. G., THE INFLUENCE OF SALT ADDITIVES ON THE DISSOCIATION OF DOLOMITE. [O VLIYANII PRIMESEY SOLEY NA DISSOTSIATSYU DOLOMITA]. Doklady Akademii Nauk SSSR, 1943. 38 (1).

[3] Berg, L. G., AREA METHODS IN QUANTI-

TATIVE THERMOGRAPHIC STUDIES. [OB IZMERENII PLOSHCHADEY NA TERMOGRAMMAKH DLYA KOLICHESTVENNYKH RASCHETOV I OPREDELENYA TEPLOT REAKTSY]. Doklady Akademii Nauk SSSR, 1945. 49 (9).

[4] Berg, L. G., RAPID QUANTITATIVE METHODS IN SOLUTION STUDIES. [SKOROSTNOY KOLICHESTVENNY FAZOVYY ANALIZ]. Academy of Science of the USSR, 1952.

[5] Bruyevich, S. V., and A. I. Belev., CALCIUM AND MAGNESIUM CARBONATES IN THE BOTTOM SEDIMENTS OF THE SOUTHERN CASPIAN. [KARBONATY KALTSYA I MAGNIYA V DONNYKH OTLOZHENYAKH YUZHNOGO KASPIYA]. Transactions of the Commission for the Integrated Study of the Caspian Sea, Academy of Science of the USSR, 1941. No. 14.

[6] Bushinsky, G. I., STRUCTURE AND TEXTURE OF MARLS AND CHALKS. [STRUKTURY I TEKSTURA MERGELNO-MELOVYKH POROD]. Bulletin of the Moscow Natural History Society: Section of Geology, 1947. 22 (1).

[7] Ilinsky, V. P., Klebanov, G. S., and F. F. Bader., SALT LAKE KUULI. [SOLENOYE OZERO KUULI]. Transactions of the Salt Laboratory, Academy of Science of the USSR, 1932. No. 3.

[8] Ilinsky, V. P., Klebanov, G. S., and Ya. V. Blyumberg., CHEMISTRY OF THE WATER OF THE KARA-BOGAZ-GOL. [GIDROKHIMYA KARABUGAZSKOGO ZALIVA]. Transactions of the Salt Laboratory of the All-Union Halide Research Institute, Academy of Science of the USSR, 1936. No. 5.

[9] Kazakov, A. V., and K. S. Andrianov., METHODS OF THERMAL ANALYSIS. [METODIKA TERMICHESKOGO ANALIZA]. V. I. Vernadsky Testimonial Symposium Volume, Academy of Science of the USSR, 1936. pp. 833-858.

[10] Krotov, V. P., DOLOMITES: THEIR ORIGIN, CONDITIONS OF STABILITY IN THE EARTH'S CRUST, AND CHEMICAL ALTERATION - IN THE LIGHT OF STUDIES OF THE UPPER KAZANIAN DOLOMITES IN THE VICINITY OF KAZAN. [DOLOMITY, IKH OBRAZOVANYE, USLOVIYA USTROYCHIVOSTI V ZEMNOY KORE I IZMENENYA V SVYAZI S IZUCHENYEM DOLOMITOV VERKHNIKH GORIZONTOV KAZANSKOGO YARUSA V OKRESTNOSTYAKH G. KAZANI]. Transactions of the Natural History Society at the Kazan State University, 1925. 50 (6).

[11] Makhayev, V. N., A CONTRIBUTION ON THE FOSSIL ALGAE OF THE USSR. [MATERIALY K POZNANYU ISKOPAYEMYKH VODOROSLEY SSSR]. Bulletin of the Moscow Natural History Society, 1940. 18 (5-6).

[12] MASLOV, V. P., THE GEOLOGY OF CARBONATE ALGAE. [KARBONATNY VODOROSLI KAK GEOLOGICHESKY FAKTOR]. Problemy Sovetskoy Geologii, 1935. No. 5.

[13] Maslov, V. P., STROMATOLITHS OF THE SOUTHERN URALS. [O STROMATOLITOVYKH POSTROYKAKH NA YUZHNOM URALE]. Transactions of the Geological Institute of the Academy of Science of the USSR, 1936. 5.

[14] Maslov, V. P., SOME PALEOZOIC ALGAE OF THE SOUTHERN URALS. [NEKOTORYE PALEOZOYSKYE KARBONATNYE YUZHNOGO URALA]. Transactions of the All-Union Mineral Resources Research Institute, ONTI, 1935. No. 72.

[15] Potapenko, S. V., THERMAL DISSOCIATION OF LIMESTONES, DOLOMITES, AND MAGNESITES. [TERMICHESKAYA DISSOTSIATSYA IZVESTNYAKOV, DOLOMITOV I MAGNEZITOV]. Zhurnal Prikladnoy Khimii, 1932. 5 (5-7).

[16] Pustovalov, L. V., GEOCHEMICAL FACIES AND THEIR SIGNIFICANCE IN GENERAL AND APPLIED GEOLOGY. [GEOKHIMICHESKYE FATSII I IKH ZNACHENYE V OBSHCHEY I PRIKLADNOY GEOLOGII]. Problemy Sovetskoi Geologii, 1933. No. 1.

[17] Pustovalov, L. V., RATOVKITE OF THE UPPER VOLGA VALLEY. [RATOVKIT VERKHNEGO POVOLZHYA]. The Academy of Science of the USSR, 1937.

[18] Pustovalov, L. V., PETROGRAPHY OF THE SEDIMENTARY ROCKS. [PETROGRAFYA OSADOCHNYKH POROD]. Parts I and II, 1940.

[19] Rozhkova, E. V., and N. V. Soloviev., THE ORIGIN OF SPHERULITIC AND OOLITIC DEPOSITS. [K VOPROSU OBRAZOVANYA SFEROLITOVYKH I OOLITOVYKH STRUKTOR]. Bulletin of the Moscow Natural History Society: Section of Geology, 1937. 15 (4).

[20] Sapozhnikov, D. G., LIMESTONES AND

DOLOMITES IN THE BOTTOM SEDIMENTS OF LAKE BALKHASH. [IZVESTKOVO DOLOMITOVY IL OZERA BALKHASH]. Doklady Akademii Nauk, SSSR, 1942. 36 (4-5).

[21] Sapozhnikov, D. G., RECENT SEDIMENTS AND THE GEOLOGY OF LAKE BALKHASH. [SOVREMENNYE OSADKI I GEOLOGYA BALKHASH]. Transactions of the Institute of Petroleum Geology (IGN), 1951. No. 132.

[22] Smirnov, N. N., PETROGRAPHIC STUDIES IN THE CARBONIFEROUS OF THE MOSCOW BASIN. [PETROGRAFICHESKYE ISSLEDOVANYA V PODMOSKOVNOM KARBONE]. Transactions of the Institute of Mineralogy, Petrography, and Crystallography of the Faculty of Physics and Mathematics, Moscow State University, 1930. No. 9.

[23] Soloviev, N. V., AN INVESTIGATION OF THE ORIGIN OF DOLOMITE "FLOUR" IN THE VICINITY OF THE KUIBYSHEV DAM. [ISSLEDOVANYE PO VOPROSU PROIZKHOZHDENYA DOLOMITOVOY-MUKI V RAYONE STROITELSTVA KUYBYSHEVSKOY PLOTINY]. Doklady Akademii Nauk SSSR, 1941. 30 (6).

[24] Strakhov, N. M., DOLOMITIC SEDIMENTS OF LAKE BALKHASH AND THEIR SIGNIFICANCE FOR THE STUDY OF THE ORIGIN OF DOLOMITE. [DOLOMITOVYE OSADKI OZERA BALKHASH I IKH ZNACHENYE DLYA POZNANYA PROTSESSA DOLOMITOOBRAZOVANYA]. Sovetskaya Geologia, 1945. No. 4.

[25] Strakhov, N. M., THE SIGNIFICANCE OF RECENT LACUSTRINE AND LAGOONAL DEPOSITS FOR THE STUDY OF SEDIMENTATIONAL PROCESSES. [O ZNACHENII SOVREMENNYKH OZERNYKH I LAGUNNYKH VODOYEMOV DLYA POZNANYA PROTSESSOV OSADKOOBRAZOVANYA]. Izvestya Akademii Nauk SSSR, 1945. No. 1.

[26] Strakhov, N. M., THE GEOLOGY OF THE KUNGURIAN OF THE ISHIMBAI DISTRICT. [GEOLOGYA KUNGURA ISHIMBAYEVSKOGO RAYONA]. Moscow Natural History Society, 1947. Part I.

[27] Strakhov, N. M., RECENT LAGOONAL DEPOSITS AND THEIR SIGNIFICANCE FOR THE STUDY OF THE ORIGIN OF DOLOMITE. [KARBONATY V SOVREMENNYKH LAGUNNYKH VODOYEMAKH I IKH ZNACHENYE DLYA PROBLEMY DOLOMITOOBRAZOVANYA]. Bulletin of the Moscow Natural History Society; Section of Geology, 1947. 22 (4).

[28] Strakhov, N. M., THE OCCURRENCE OF IRON IN MARINE AND LACUSTRINE SEDIMENTS. [RASPREDELENYE ZHELEZA V OSADKAKH MOREY I OZER]. Izvestya Akademii Nauk SSSR: Geological Series, 1948. No. 4.

[29] Strakhov, N. M., LIMESTONE AND DOLOMITE FACIES IN RECENT AND ANCIENT WATER-LAID SEDIMENTS. [IZVESTKOVO-DOLOMITOVYE FATSII SOVREMENNYKH I DREVNIKH VODOYEMOV]. Transactions of the Geological Institute of the Academy of Science of the USSR, 1951. No. 124.

[30] Strakhov, N. M., THE PROBLEM OF THE DISTRIBUTION AND ACCUMULATION OF THE MAIN CHEMICAL COMPONENTS IN RECENT AND ANCIENT WATER-LAID SEDIMENTS. [PROBLEMA RASPREDELENYA I NAKOPLENYA OSNOVNYKH KHIMICHESKIKH KOMPONENTOV V OSADKAKH SOVREMENNYKH I DREVNIKH VODOYEMOV]. Transactions of the All-Union Conference on Sedimentary Rocks, the Academy of Science of the USSR, 1952. No. 1.

[31] Strakhov, N. M., and A. I. Tsvetkov., MAGNESITE AND ITS GENESIS IN SEDIMENTARY ROCKS. [O MAGNEZITE I EGO GENEZISE V OSADOCHNYKH PORODAKH]. Mineralogical Society Notes, Series two, 1944. 73 (4).

[32] Strakhov, N. M., and A. I. Tsvetkov., THE DEPOSITION OF CARBONATE MINERALS IN HIGH-SALINITY LAGOONS. [O PARAGENEZISE KARBONATNYKH MINERALOV V OTLOZHENIYAKH SOLENYKH LAGUNNYKH VODOYEMOV]. Lithological Compendium, The Moscow Natural History Society, 1946.

[33] Tatarsky, V. B., A CONTRIBUTION ON THE ORIGIN OF DOLOMITE. [K VOPROSU O PROISKHOZHDENII DOLOMITA]. Notes of the Russian Mineralogical Society, Part 66, 1937. No. 4.

[34] Tatarsky, V. B., THE ORIGIN OF DOLOMITIC RESERVOIR FORMATION AND THE LITHOLOGY OF CARBONATE PAY FORMATIONS IN CENTRAL ASIA. [LITOLOGYA NEFTENOSNYKH KARBONATNYKH POROD SREDNEY AZII I PROISKHOZHDENYE NEFTENOSNYKH DOLOMITOV]. Transactions of the Petroleum Exploration and Research Institute (NGRI), Series A, 1939. No. 112.

[35] Tatarsky, V. B., CRYSTAL OPTICS AND IMMERSION METHODS. [KRISTALLOOPTIKA I IMMERSIONNY METOD OPREDELENYA VESHCHESTVA]. Leningrad State University, 1949.

[36] Tatarsky, V. B., METHODS OF DETERMINING ROCK-FORMING CARBONATES. [METODY OPREDELENYA PORODOOBRAZUYUSHCHIKH KARBONATNYKH MINERALOV]. Gostoptekhizdat, 1952.

[37] Teodorovich, G. I., DOLOMITES IN THE ISHIMBAI REEFS. [DOLOMITIZATSYA RIFOVYKH OBRAZOVANIY ISHIMBAYEVSKOVO RAYONA]. Doklady Akademii Nauk SSSR, 1942. 34 (6).

[38] Teodorovich, G. I., PORE STRUCTURE AND PERMEABILITY IN CARBONATE PETROLEUM RESERVOIRS. [STRUKTURA POROVOGO PROSTRANSTVA KARBONATNYKH KOLLEKTOROV NEFTI I IKH PRONITSAYEMOST]. Doklady Akaemii Nauk SSSR, 1943. 39 (6).

[39] Teodorovich, G. I., THE CHIEF VARIETIES OF CHEMICAL $CaCO_3$ IN CARBONATE SEDIMENTS. [OSNOVNYE TIPY KHEMOGENNOGO $CaCO_3$ KARBONATNYKH OSADOCHNYKH POROD]. Doklady Akademii Nauk, SSSR, 1945. 49 (4).

[40] Teodorovich, G. I., DOLOMITES IN THE UPPER PALEOZOIC OF THE VOLGA-URALS PROVINCE. [O DOLOMITE V VERKHNEM PALEOZOYE URALO-VOLZHESKOY OBLASTI]. Doklady Akademii Nauk, SSSR, 1945. 49 (7).

[41] Teodorovich, G. I., REPLACEMENT DOLOMITES IN THE UPPER PALEOZOIC OF THE VOLGA-URALS PROVINCE. [DOLOMIT ZAMESHCHANYA V VERKHNEM PALEOZOYE URALO-VOLZHESKOY OBLASTI]. Bulletin of the Moscow Natural History Society: Section of Geology, 1945. 20 (3-4).

[42] Teodorovich, G. I., THE ORIGIN OF SUTURAL TEXTURES. [O PROISKHOZHDENII SUTURO-STILOLITOVYKH POVERKHNOSTEY]. Doklady Akademii Nauk SSSR, 1945. 50.

[43] Teodorovich, G. I., THE ORIGIN OF DOLOMITES IN SEDIMENTARY DEPOSITS. [O GENEZISE DOLOMITA OSADOCHNYKH OBRAZOVANY]. Doklady Akademii Nauk SSSR, 1946. 53 (9).

[44] Teodorovich, G. I., SEDIMENTARY GEOCHEMICAL FACIES. [OSADOCHNYE GEOKHIMICHESKYE FATSII]. Bulletin of the Moscow Natural History Society: Section of Geology, 1947. 22(1).

[45] Teodorovich, G. I., CARBONATE FACIES OF THE UPPER CARBONIFEROUS AND LOWER PERMIAN OF THE VOLGA-URALS PROVINCE. [KARBONATNYE FATSII NIZHNEY PERMI-VERKHNEGO KARBONA URALO-VOLZHSKOY OBLASTI]. Materials on the geology of the USSR, the Moscow Natural History Society, 1949. No. 13 (17).

[46] Teodorovich, G. I., LITHOLOGY OF THE UPPER PALEOZOIC CARBONATES OF THE VOLGA-URALS PROVINCE. [LITOLOGYA KARBONATNYKH POROD PALEOZOYA URALO-VOLZHSKOY OBLASTI]. Akademii Nauk SSSR, 1950.

[47] Teodorovich, G. I., THE FUNDAMENTAL LAWS OF SEDIMENTATION, IN THE STATE OF THE STUDY OF SEDIMENTARY ROCKS. [OB OSNOVNYKH ZAKONOMERNOSTYAKH OSADKOOBRAZOVANYA]. Symposium volume, Akademii Nauk, SSSR, 1951.

[48] Tsvetkov, A. I., THE THERMAL PROPERTIES OF ANHYDROUS CARBONATES. [TERMOANALITICHESKYE KHARAKTERISTIKI BEZRODNYKH KARBONATOV]. Transactions of the Institute of Geological Science, Akademii Nauk, SSSR: Petrography Series, 1949. No. 106.

[49] Tsvetkov, A. I., ANHYDROUS CARBONATES. [BEZRODNYKH KARBONATOV]. Transactions of the Institute of Geological Science, Akademii Nauk, SSSR: Petrography Series, 1949. No. 120.

[50] Vinogradov, A. P., Ronov, A. B., and B. M. Ratynsky., VARIATIONS IN THE CHEMISTRY OF THE CARBONATES OF THE RUSSIAN PLATFORM. [IZMENENYE KHIMICHESKOGO SOSTAVA KARBONATNYKH POROD RUSSKOY PLATFORMY]. Izvestya Akademii Nauk SSSR: Seria Geologicheskaya, 1952. No. 1.

[51] Vinogradov, A. P., Ronov, A. B., and B. M. Ratynsky., EVOLUTION OF THE CHEMICAL COMPOSITIONS OF CARBONATES. [EVOLYUTSYA KHIMICHESKOGO SOSTAVA KARBONATNYKH POROD]. Transactions of the All-Union Conference on Sedimentary Rocks, Akademii Nauk, SSSR, 1952. No. 1.

[52] Yanatieva, O. K., SOLUBILITY CHARACTERISTICS OF THE SYSTEM (CaMg) CO_3-SO_4-H_2O. [RASTVORIMOST V SIS-

TEMYE (CaMg) CO_3-SO_4-H_2O]. Doklady Akademii Nauk SSSR, 1949. 67 (3).

[53] Yanatieva, O. K., THE SOLUBILITY OF DOLOMITE IN AQUEOUS SOLUTIONS OF SALTS. [RASTVORIMOST DOLOMITA V VODNYKH RASTVORAKH SOLEY]. Transactions of the Physical-Chemical Analysis Section, 1950. 20.

Strakhov, N. M., Brodskaya, N. G., Knyaseva, L. M., Razzhivina, A. N., Rateev, M. A., Sapozhnikiv, D. G., and E. S. Shishova. FORMATION OF SEDIMENTS IN RECENT BASINS: A symposium, Moscow, 1954. 791 pp. A review by George V. Chilingar, University of Southern California.

These diagrams and tables are intended to supplement the information presented by Prof. Chilingar in a summary entitled, "The Black Sea and its sediments."[1]

In this paper, the reviewer briefly describes the bottom topography, temperature variations, chemistry, and sediments of the Black Sea.

A topographic map of the Black Sea bottom is included and ranges to greater than 2000 meters in depth. Seasonal temperature fluctuations decrease in amplitude with increasing depth. In deeper waters, a constant temperature of 9°C is observed. This temperature distribution is related to "the influx of Mediterranean waters, which, because of the higher density, remain at the bottom."

The chemical composition of Black Sea waters is described in terms of variation with depth; a brief discussion of the causes of variation is included.

The distribution of sediments is outlined. Two types mentioned in the present paper are described: (1) "Midievyy mud": A silty clay containing an abundance of Mytilus edulis; (2)"Fazeolinovyy mud": dark clay containing conspicuous Modiola faseolina.

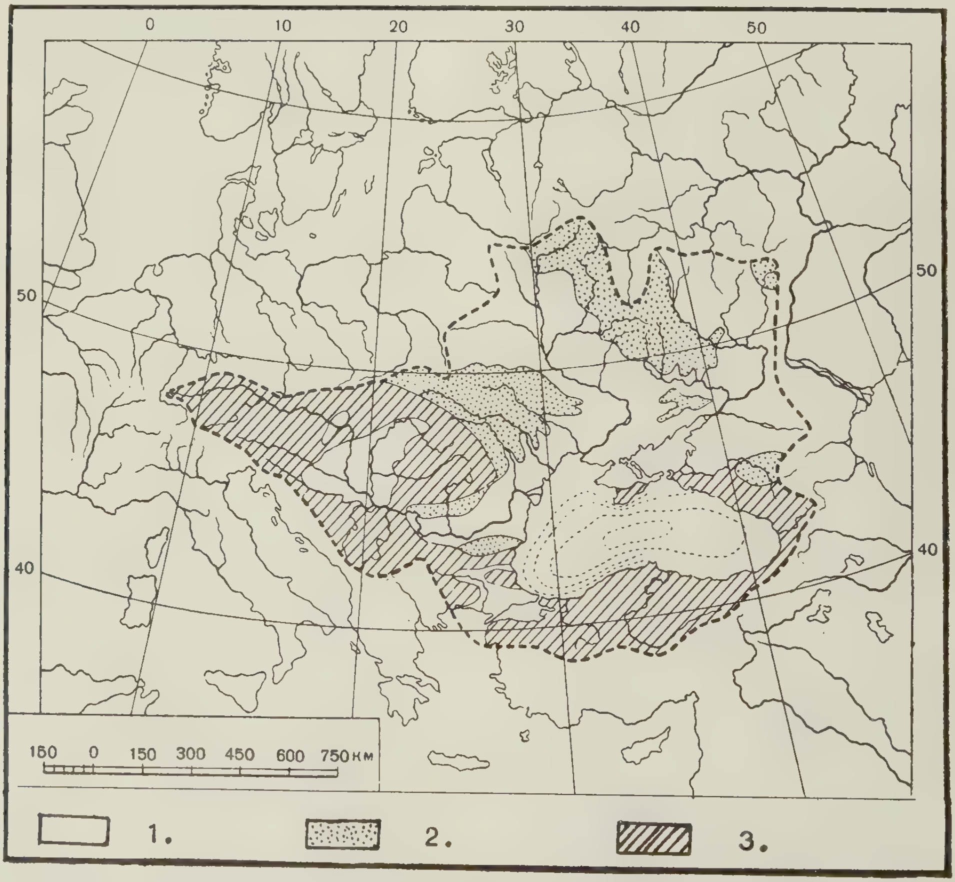

FIGURE 1. Drainage basin of the Black Sea, after Strakhov, 1954, p.83. (1) 0-200 m elevation; (2) 200-500 m elevation; (3) above 500 m elevation. Total drainage area 1,864,000 km^2; area of the Black Sea - 500,000 km^2; volume of water - 529,954 km^3.

[1]American Association of Petroleum Geologists Bulletin, 1956. 40 (11):2765-2769.

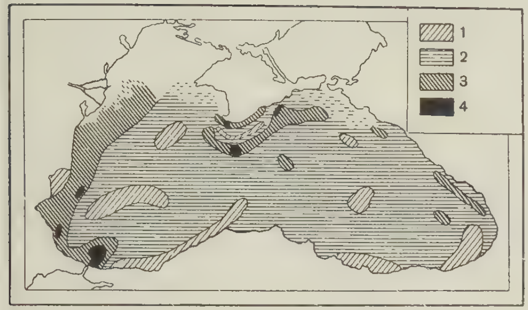

FIGURE 2. Horizontal distribution of plankton in the upper layer (0-100 m) of Black Sea in mg/m^3, after V.N. Nikitin, 1949, in Strakhov, 1954, p.86. (1) 50-100, (2) 100-150, (3) 150-200, and (4) 200-300.

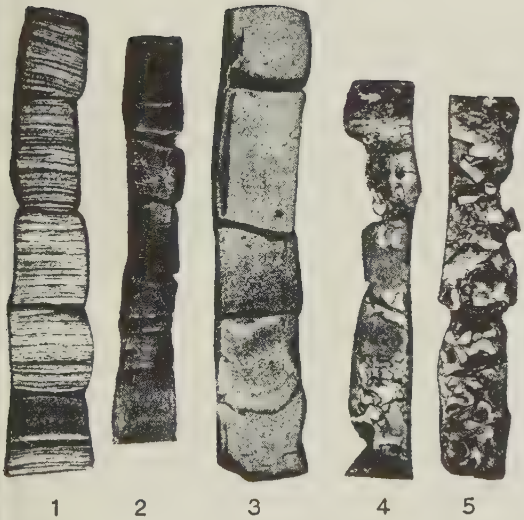

FIGURE 4. Cores of recent sediments in Black Sea (after Arkhangelsky and Strakhov, 1938). (1) calcareous ooze; (2) black ooze; (3) gray clay (ancient "Novoevksinskaya"); (4) fazeolinovyy ooze; and (5) midievyy ooze. Shallow-water deposits are reduced 2 times, whereas deep-water deposits are reduced 1-1/2 times.

TABLE I. Average chemical composition of gray deep-water clay (in %), after Strakhov, 1954, p. 91.

Components	Number of analyses	Content, %
Mineral insoluble residue	38	55.62-84.59 (av. 75.0)
$CaCO_3$	38	7.21-34.34 (av. 14.3)
Fe	15	3.12-6.72 (av. 4.83)
Mn	15	0.04-0.14 (av. 0.066)
P	15	0.04-0.15 (av. 0.11)
$C_{org.}$	7	1.51-2.08 (av. 1.74)

TABLE II. Average chemical composition of midievyy mud (in %), after Strakhov, 1954, p.91.

Components	Number of analyses	Content, %
Mineral insoluble residue	13	53.76-86.10 (av. 75.8)
$CaCO_3$	13	7.31-39.18 (av. 16.3)
Fe	1	4.76
Mn	1	0.04
P	1	0.10
$C_{org.}$	9	0.71-4.97 (av. 2.14)

TABLE III. Average chemical composition of fazeolinovyy mud (in %), after Strakhov, 1954, p. 91.

Components	Number of samples	Content, %
Mineral insoluble residue	22	54.3-84.95 (av. 73.00)
$CaCO_3$	22	7.33-47.88 (av. 19.1)
Fe	4	3.81-8.76 (av. 5.25)
Mn	4	0.02-0.12 (av. 0.055)
P	4	0.09-0.11 (av. 0.10)
$C_{org.}$	8	0.62-2.15 (av. 1.61)

TABLE IV. Average chemical composition of clayey-calcareous mid (in %), after Strakhov, 1954, p. 93.

Components	Number of analyses	Content, %
Mineral insoluble residue	9	40.86-52.53 (av. 49.7)
$CaCO_3$	9	35.5-43.0 (av. 38.41)

TABLE V. Average chemical composition of calcareous-clayey mud (in %), after Strakhov, 1954, p. 95.

Components	Number of analyses	Content, %
Mineral insoluble residue	14	18.42-34.36 (av. 28.3)
$CaCO_3$	14	50.37-72.47 (av. 58.7)
Fe	7	2.63-4.67 (av. 3.54)
Mn	7	0.04-0.05 (av. 0.04)
P	7	0.04-0.09 (av. 0.07)
$C_{org.}$		
in clayey variety	3	3.25-3.80 (av. 3.68)
in typical variety	5	3.72-5.23 (av. 4.54)

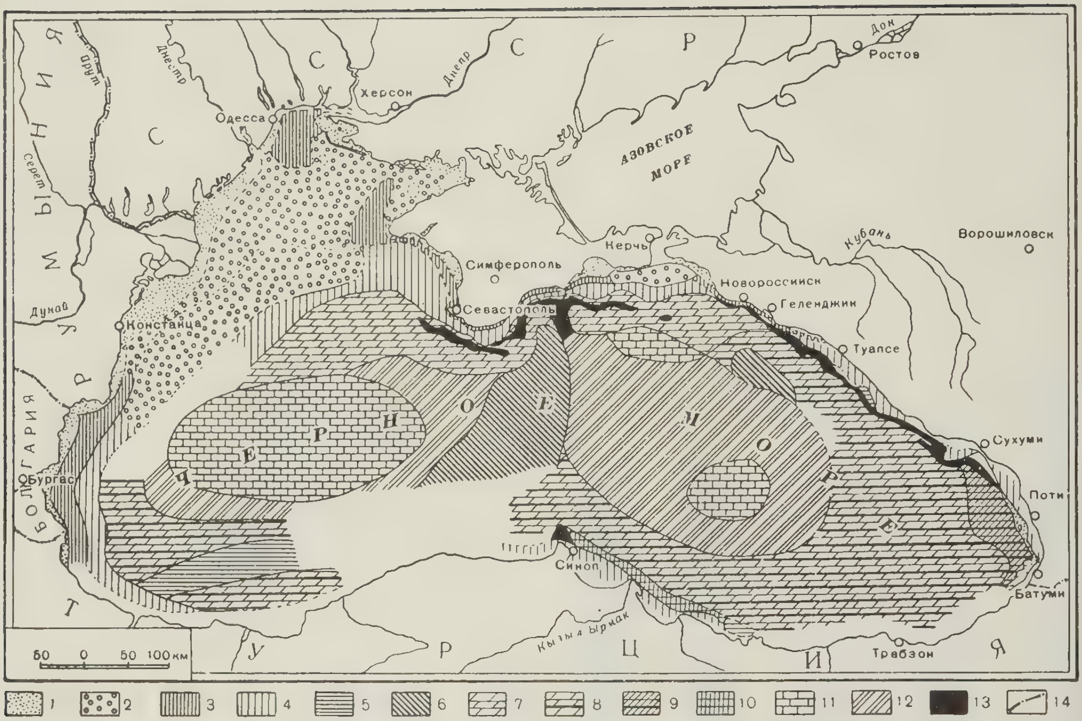

FIGURE 3. Distribution of recent sediments in Black Sea, after Strakhov, 1954, p. 89. (1) sand; (2) coquina; (3) midievyy mud; (4) fazeolinovyy mud; (5) gray slightly-calcareous clayey mud; (6) same as 5 with calcareous-clayey mud interlayers; (7) clayey-calcareous mud; (8) same as 7 with slightly-calcareous clayey mud interlayers (number of interlayers increases on approaching southern shores); (9) same as 7 with sand interlayers; (10) same as 7 with clayey mud interlayers; (11) calcareous-clayey mud; (12) same as 11 with clayey mud interlayers; (13) areas devoid of recent sediments; and (14) international boundaries.

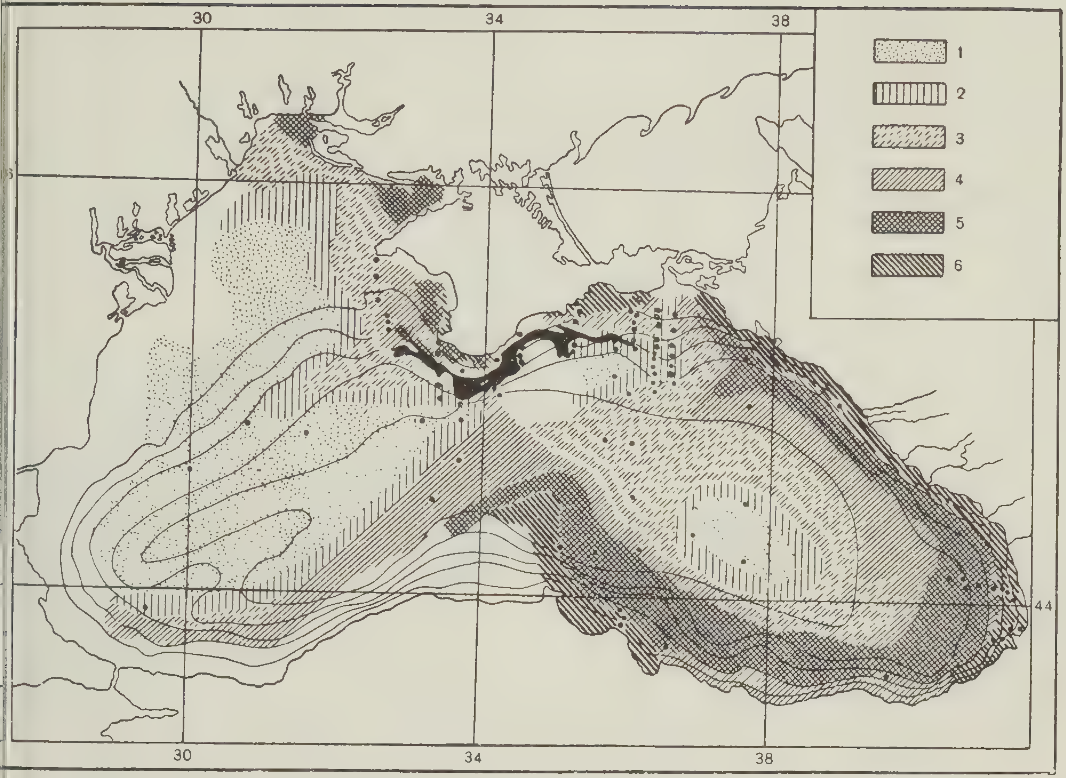

FIGURE 5. Distribution of absolute amounts of terrigenous material, deposited in Recent epoch (in g/cm^2), after Strakhov, 1954, p. 94. (1) 0-10; (2) 10-20; (3) 20-50; (4) 50-100; (5) 100-200; (6) above 200; black areas are devoid of recent sediments.

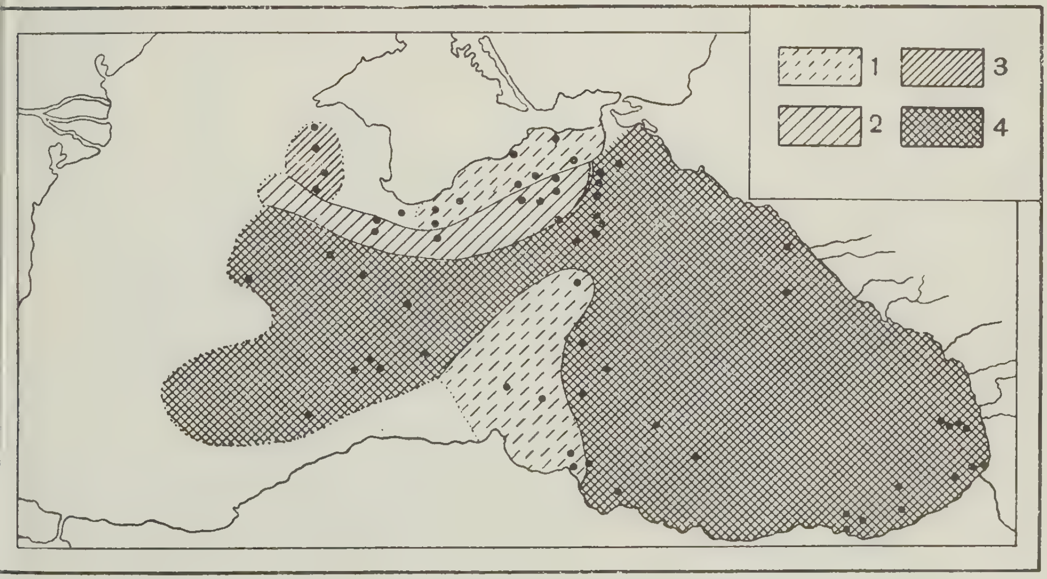

FIGURE 6. Distribution of clay minerals in Black Sea sediments, after M.A. Rateev, in Strakhov, 1954, p. 100. (1) montmorillonite with chlorite; (2) montmorillonite with admixture of hydromicas; (3) hydromicas with small admixture of halloysite; and (4) hydromicas with small admixture of kaolinite.

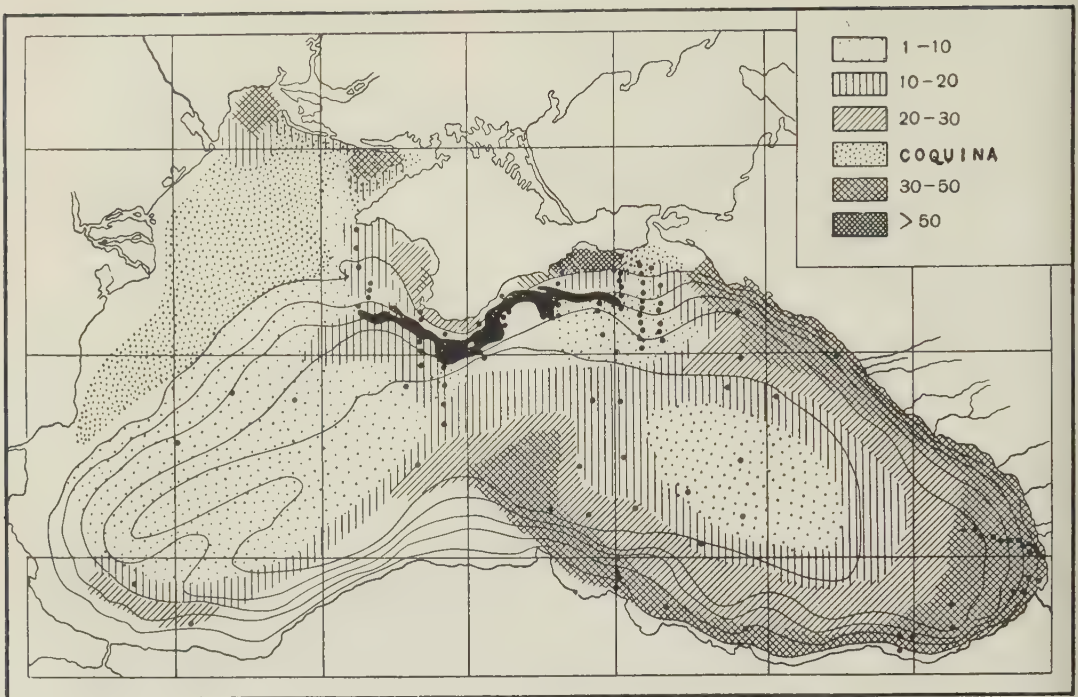

FIGURE 7. Distribution of absolute amounts of $CaCO_3$ (in g/cm^2), deposited in the Black Sea during the recent period of its life (2500 years), after Strakhov, 1954, p. 102. Black areas - devoid of recent sediments; dotted areas - coquina.

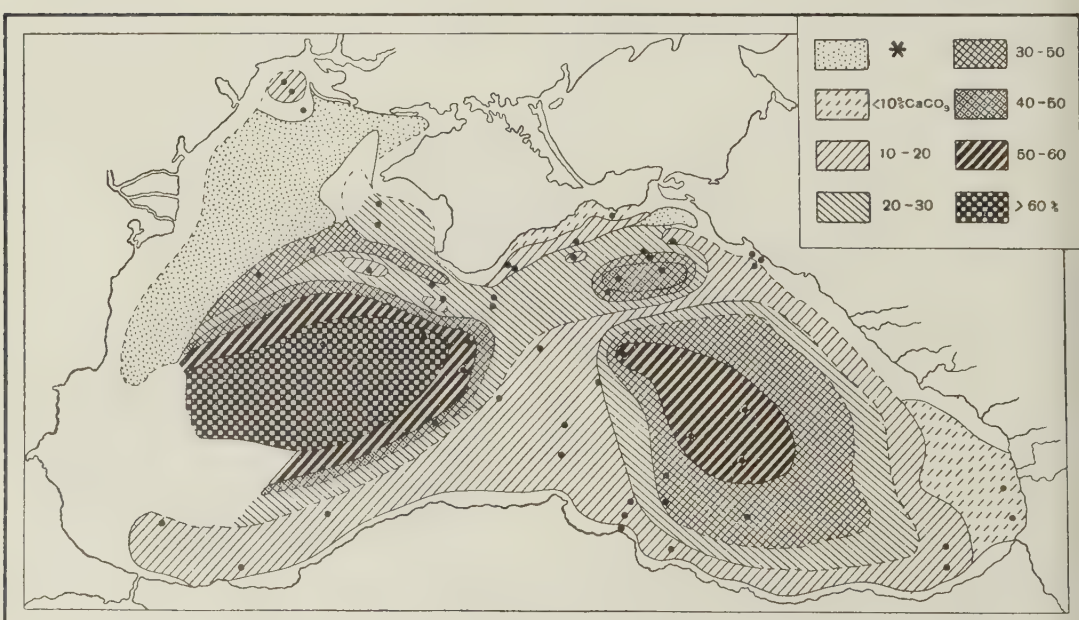

FIGURE 8. Distribution of $CaCO_3$ in recent deposits of Caspian Sea, in % of total dry weight (after Strakhov, 1954, p. 107). * Dotted areas - coquina.

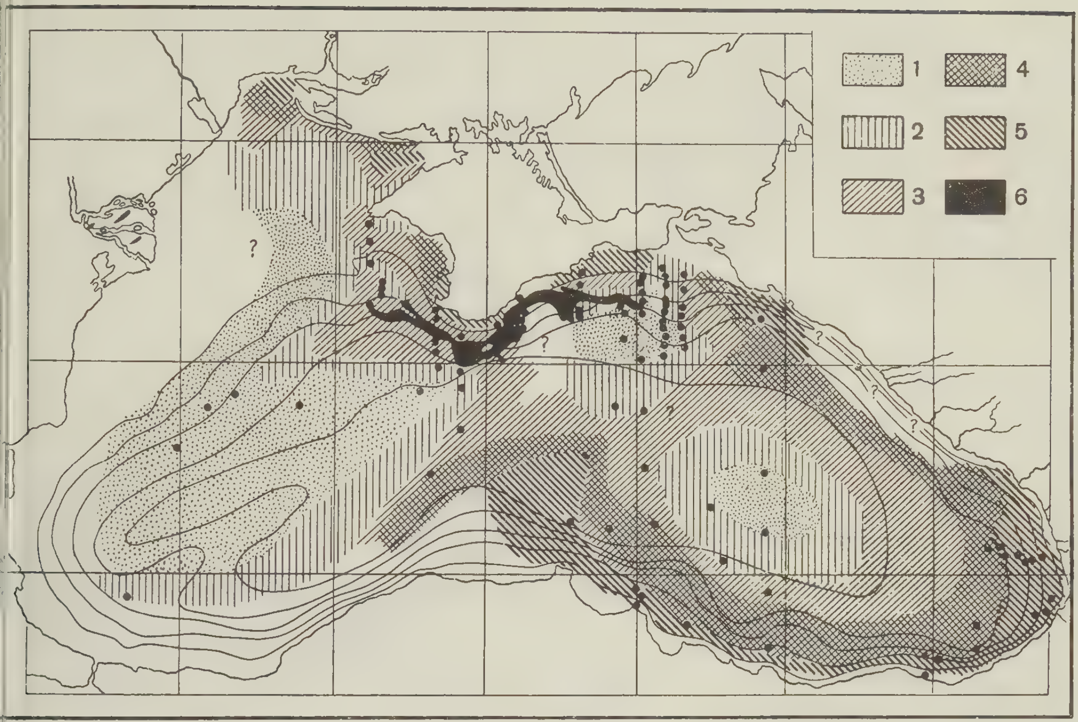

FIGURE 9. Accumulation of organic matter in 2500 years, in g/cm^2 (after Strakhov, 1954, p.112). (1) less than 0.6; (2) 0.6-1.0; (3) 1.0-2.0; (4) 2.0-4.0; (5) above 4.0; and (6) recent deposits destroyed by slides.

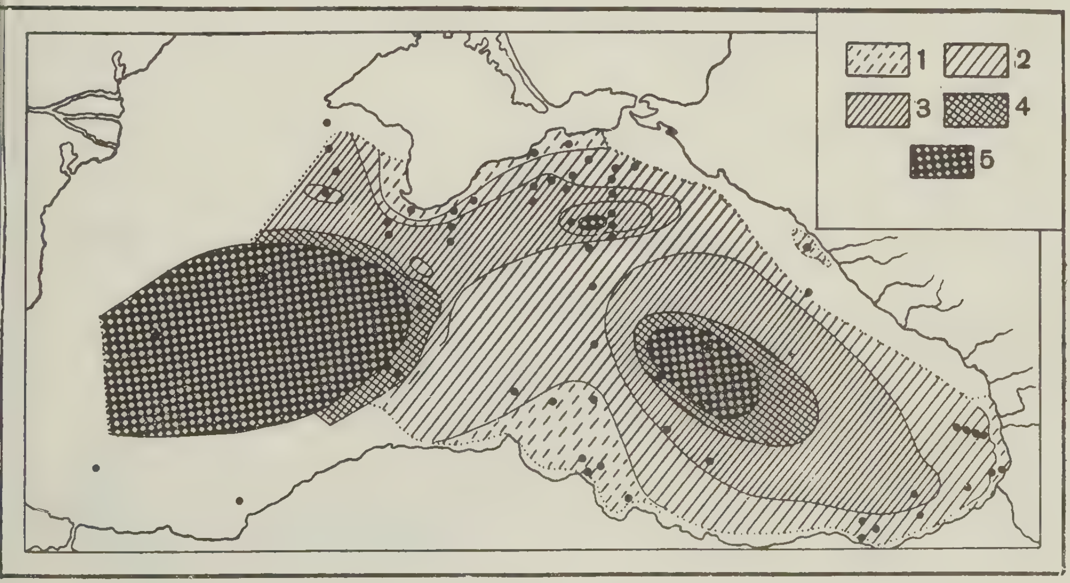

FIGURE 10. Distribution of organic carbon in Black Sea sediments (in %), after Strakhov, 1954, p.114. (1) less than 1%; (2) 1-2%; (3) 2-3%; (4) 3-4%; and (5) above 4%.

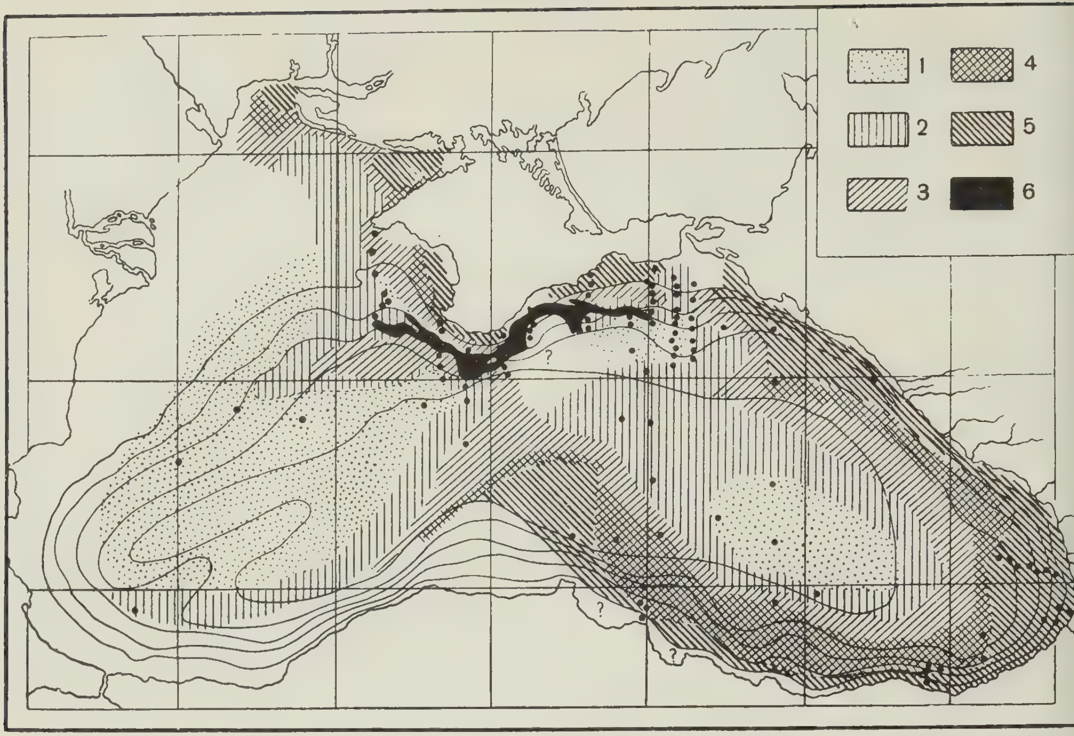

FIGURE 11. Distribution of iron accumulated in recent time (g/cm^2), after Strakhov, 1954, p.122. (1) 0-1; (2) 1-3; (3) 3-5; (4) 5-7; (5) above 7; and (6) recent deposits destroyed by slides. Figure 11 shows that iron is deposited in Black Sea as fragmental material, following the rules of mechanical deposition.

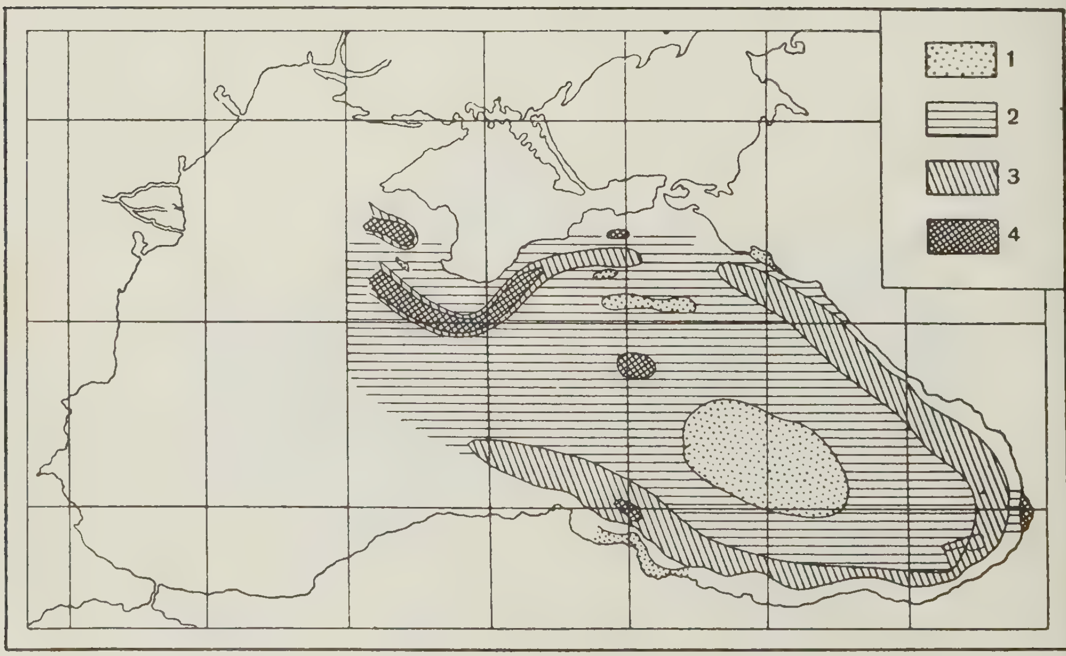

FIGURE 12. Percentage distribution of iron in surface layer of recent deposits (% of sediment), after Strakhov, 1954, p. 124. (1) less than 3.5%; (2) 3.5-5.0%; (3) 5.0-6.0%) and (4) above 6%.

TABLE VI - Combined H_2S content in Black Sea muds (in %), after P. T. Danilchenko, 1926, in Strakhov, 1954, p. 120.

Sample	Depth, m	H_2S content, %
1	450	0.148
2	430	0.134
3	around 1,000	0.135
4	around 2,000	0.055
5	around 2,150	0.054

TABLE VII - Average Mn/Fe and P/Fe ratios in Black Sea muds, after Strakhov, 1954, p. 126.

Sediment	Mn/Fe	P/Fe
Fazeolinovyy mud	0.010	0.019
Gray clay	0.014	0.021
Deep-water gray sands	0.020	0.016
Deep-water sandy mud	0.013	0.020
Clayey-calcareous mud	0.013	0.022
Calcareous mud	0.011	0.020

TABLE VIII. Vanadium content (%) in Black Sea muds, after A.D. Arkhangelsky 1930, in Strakhov, 1954, p. 128.

Sediment	C	$CaCO_3$	Detrital material	V	V/detrital ratio	V/C ratio
Clayey-calcareous mud	2.48	18.80	77.0	0.02	0.00025	0.008
Same as above	3.70	10.67	83.1	0.03	0.00036	0.008
Calcareous mud	3.99	40.94	52.4	0.04	0.00077	0.010
Black mud	10.65	14.23	71.7	0.06	0.00085	0.007
Calcareous mud	3.90	42.36	51.1	0.03	0.00059	0.008
Black mud	10.54	10.27	72.1	0.04	0.00055	0.004
Black mud	9.91	3.29	80.2	0.06	0.00075	0.006
Gray unlayered clay	3.11	2.51	92.2	0.03	0.00033	0.010
Clay with Dreissensia	0.85	35.65	63.0	0.01	0.00016	0.012

Notes on international scientific meetings

SYMPOSIUM ON GEOCHEMISTRY OF TRACE ELEMENTS

Moscow, December 1957

The conduct of trace elements during the formation of intrusive rocks has in recent years begun to attract the attention of scientists throughout the world.

The Institute of Geochemistry and Analytical Chemistry, named in honor of V. I. Vernadsky, organized a symposium on geochemistry of trace elements in intrusive rocks related to the problems of petrogeny, in December, 1957. The symposium was initiated by A. P. Vinogradov, a member of the Academy of Sciences, and it took place under his chairmanship. Great geochemists and many leading petrographers and crystal chemists of the Soviet Union and a number of foreign countries took part in the symposium. The foreign countries were represented by the following professors: L. C. Arens (Capetown, Union of South Africa), D. Djushka (People's Republic of Rumania), E. Ingerson (University of Texas, USA), Kochta (People's Republic of Czechoslovakia), N. N. Nikiforov (Sofia, People's Republic of Bulgaria), M. Savul (Iasi, People's Republic of Rumania), E. Sadetsky-Kardosh (Cegled, People's Republic of Hungary), and K. Smulikovsky (Warsaw, People's Republic of Poland).

The problem put forth before the symposium led to discussions on the subject of how, at the present level of our knowledge, the distribution of trace elements in igneous rocks may serve as an indicator of conditions that existed during the formation of intrusive complexes. Therefore, the greatest attention was given to the conduct of trace elements during the magmatic development of "pure line," i. e., during the formation of intrusive complexes largely composed of granitoids.

The symposium, as a great scientific event, also deserves attention from the organizational point of view. A limited number of scientists, specializing in this particular scientific field or in related fields, were invited to the symposium. A substantial number of representatives from various scientific organizations interested in the subject of the symposium attended as guests.

The sessions of the symposium were organized in the form of businesslike exchanges of opinion. This was demonstrated, for example, by the strictly limited time given to speakers and by the emphasis put on broad and diversified discussions of report and related subjects.

The majority of the reports were dedicated to a discussion of the distribution of certain elements and their groups in intrusive rocks.

Several reports of a general nature were presented during the last few sessions of the symposium.

The materials of the symposium will be published. Consequently, this article will cover only the most interesting conclusions drawn by the reporters and the sharpest moments of dispute over them.

The report presented by V. V. Shcherbina and L. F. Borisenko discussed the distribution of scandium and vanadium in intrusive rocks. Similarities and differences in the distribution of these elements in rocks and minerals are interpreted in the report largely from point of view of crystal chemistry. The reporters emphasized that both elements are typically bound to basic magma but that their conduct in rocks differs. The reporters explain the concentration of scandium in dark-colored silicates (especially clinopyroxenes and hornblendes), garnets and zircons, and the concentration of vanadium largely in titanomagnetite and biotite, and to a lesser extent in pyroxenes and amphiboles, by the isomorphic peculiarities of these elements. They reviewed various types of iso- and heterovalent isomorphism, which, according to them, explain the entrance of scandium and vanadium into the crystal structure of rock-forming minerals. They also reviewed the dependence of the scandium and vanadium distribution in minerals on general peculiarities of the chemistry of rocks (the content of aluminum, iron, magnesium, and others), alkaline concentration (which opposes Sc and V concentration, depending on the chemical properties of the latter), the composition of anions in the mineral-forming compounds. They presented an interesting but still a preliminary concept concerning the concentration of V in basic dikes (diabases) in greater amounts than in intrusive gabbros and effusive basalts.

The report by A. I. Tugarinov and E. E.

[1]Redkie elementy v izverzhennykh gornykh porodakh (k itogam simpoziuma po geokhimii redkikh elementov v svyazi s problemoy petrogenezisa). Sovetskaya Geologiya, no. 4, 1958.

Bainstein on trace elements and the coupled elements of zirconium-hafnium summarized their recent studies. Their principal conclusions are:

1. The Zr content in intrusive rocks depends first of all on alkalines. It decreases from basic to acidic rocks, and especially sharply in alkaline rocks.

2. The Zr:Hf ratio in zircon (and consequently in rocks) is very significant. It regularly increases in alkaline rocks and in rocks of alkaline (sodium) metasomatism. This indicates higher mobility of Zr than of Hf in alkaline environment; it is apparently related to the more sharply pronounced amphoteric properties of Zr. For the same reason, the authors explain the tendency of the Zr:Hf ratio to increase in margins of granitic intrusives and in pegmatites. Thus the Zr:Hf ratio is an important indicator of the origin of rocks.

3. The minerals (allanite and sphene, or monazite and xenotime), in the form of which the rare earth elements occur in granites, are predetermined by the ratio of atoms $\frac{Na + Ca + K}{4\ Al}$ and also depend on the P_2O_5 content. The reporters note the concentration of the rare earth elements in the yttrium group in Ca containing minerals and of the cerium group in phosphates (mainly in monazite).

4. Zr and Hf occur in granites in the minerals of the zircon group or in aegirine. Rare earth elements are confined largely to monazite (to a lesser extent to xenotime) or to allanite and sphene. Besides, they may occur in garnets, apatite, feldspars, and biotite.

5. The assimilation of surrounding rocks may greatly affect the concentration of Zr in granites. As far as the rare earth elements are concerned, they redistribute in the case of granitization; scattered amounts contained in assimilated rocks become concentrated.

6. Zr is very unstable in the case of autometasomatism and may be completely dissolved and extracted.

The composition of the rare earth minerals, as disclosed by the studies of the reporters, varies widely with respect to the content of particular rare earth elements and depends on the origin of the minerals concerned. The reporters believe the ratios of the rare earth elements may therefore serve as indicators.

A statement by A. I. Tugarinov, according to which the rare earth elements of the cerium group are bound to monazite, a mineral which, being concentrated in places, gets further out of petrogenic circulation, while the yttrium group, remaining in scattered form, should become relatively concentrated in younger granites, aroused serious objections.

A report by A. A. Beyus, discussing the geochemistry of beryllium in igneous rocks, presented several possibilities of heterovalent and isostructural isomorphism, which controls the entrance of Be into the crystal structure of various rock-forming minerals in intrusives. It must be noted that the reporter's statement concerning the occurrence form of Be in vesuvianite was doubted, particularly by N. V. Byelov, a member of the Academy of Sciences.

The report emphasizes the occurrence of the principal part of Be in feldspars, despite the high Be content in muscovites and dark-colored minerals. In alkaline rocks, the largest part of Be is in nepheline and feldspars. According to the report, Be becomes concentrated in granites by autopneumatolysm. The scattered, fine crystals of beryl may occur in muscovite granites containing 0.0020 to 0.0025 percent Be or more. Thus the Be content in granites may be used as an indicator of autometasomatism. In his concluding speech, the reporter pointed out that granitic complexes, to which hydrothermal-pneumatolytic deposits of Be are related, always have higher amounts of Be in rock-forming minerals (on the average, these granites contain 0.009 to 0.0014 percent Be)..

A brief report by V. I. Gerasimovsky and E. B. Znamensky concerning the Nb and Ta distribution in igneous rocks presented new data on the occurrence forms of these elements in granitoids. The reporters state that the principal part of Ti, and consequently of Ta and Nb isomorphically replacing Ti, is, in biotite granites, not related to accessory Ti minerals, but to biotite. In the course of solidification of intrusive complexes, the Nb:Ta ratio gradually decreases in later portions of the molten magma, including its dike-forming derivates. The Ta is concentrated in the remaining magma, while the Nb is taken into the crystal structure of the biotite, explaining the enrichment of granitic pegmatite largely with Ta rather than with Nb.

The established opinion that Nb greatly prevails over Ta in alkaline rocks is, according to V. I. Gerasimovsky, a mistake. He has found that, in agpaitic nepheline syenites of the Lovozersk intrusive, for instance, the Nb:Ta ratio is 9:15. This statement was criticized, however, for the data on a single intrusive cannot, apparently, be used as a general rule concerning the nepheline syenites elsewhere.

Gerasimov's report was supplemented by A. I. Ginsburg, who named a number of possi-

bilities in the geochemical history of Nb and Ta that depend on such factors as the original concentration of Nb, Ta, Ti in alkaline magmas, the presence or absence of conditions necessary for heterovalent isomorphic replacements, the chemical characteristics of a certain magma and its changes because of assimilation, which may lead to the formation of minerals that absorb Nb and Ta.

1. In the rocks containing high amounts of Ca and Ti minerals (sphene, perovskite, partially allanite), the principal parts of Nb and Ta become absorbed by these minerals because of an easy isomorphism (CaTi ⟵NaNb), and scattered in early crystallized minerals without being able to concentrate in the post-magmatic derivates.

2. In normal biotite granites containing the usual complex of accessory minerals (magnetite, zircon, apatite, monazite, and others), the principal part of Nb is absorbed by biotite However, this is the case only in magmas having adequate Li, for the valence compensation takes place according to the scheme MgTi ⟵ LiNb.

Since biotite preferably absorbs Nb, leaving Ta to concentrate in the remaining magma, especially in pegmatites, and since the same remaining magma is enriched with Li, the high Ta:Nb ratio in Li-rich pegmatites is very understandable.

3. In magmas of low Ti content, which were originally rich in Nb and Ta, the latter elements may form their own accessory minerals (preferably columbite), as is the case in granites of some regions such as the Jos Plateau in Nigeria and others.

4. In extreme alkaline environments, Nb and Ta easily form soluble complex compounds and do not become scattered in rocks of early magmatic stages. They become bound to post-magmatic autometasomatic minerals, especially to those formed during albitization.

A. I. Ginsburg also called attention to the significance of Nb:Ta ratios as an important indicator.

The report by L. V. Tauson and Z. V. Studenikova presented interesting material on the distribution of lead, zinc, and molybdenum in intrusive rocks. The reporters used a new method in studying accessory minerals in igneous rocks. They made use of large transparent slides for grain-count assays of granites.

The results of their investigations were presented in the form of monominerallic balances of certain elements.

According to them, the principal part of lead and molybdenum is bound to feldspars, that of zinc to biotite and hornblende. While there is a slight crystallochemical relationship of lead to potassium and of zinc to ferrous iron or magnesium, molybdenum has no relation to common rock-forming elements.

Isomorphic occurrence of lead and zinc in the place of common elements appears to be very limited. Consequently, the reporters conclude that a substantial, if not the principal part of Pb, Zn, and Mo do not occur isomorphically in intrusive rocks but in the form of accessory sulfides or native lead. All three elements may easily be dissolved and extracted from the rocks and minerals even by weak solvents. The reporters drew an important conclusion concerning the conduct of Pb and Zn in the course of magmatic differentiation. Using the example of the magmatic complexes in Kirgizia, the reporters demonstrated a gradual drop of the zinc content and the increase in lead from early intrusive stages to final ones. The sharply changing Zn:Pb ratio is, therefore, a valuable indicator of magmatic differentiation in granitoid complexes. The distribution of Mo in rocks of various intrusive facies does not, however, change regularly, and this excludes the use of Mo as an indicator. The conclusions drawn by the reporters led to vivid discussions. The majority of those who took part in the discussion recognized that the concept that sulfides (especially galena) in granites are accessory minerals formed during the magmatic stage of crystallization to be a disputable statement. They pointed out that no one could guarantee the independence of these minerals from later superimposed processes.

L. C. Arens (the Union of South Africa) presented new data on the Rb, Tl, and Cs content in intrusive rocks. He pointed out that the close geochemical inter-relationship of K, Rb, Tl, and Cs is caused by both their close ionic radii and the ionization potentials. The Rb:K ratio remains, according to him, about the same in all types of rocks from ultrabasic to acidic and even in meteorites (chondrites), and this indicates that the composition of the lithosphere and meteorites are related. He believes that the Rb:K ratio may serve as an important indicator of the rock's origin because of the deviations in ratio, for example, in some pegmatites.

He mentioned a sharp decrease in the Rb:K ratio in alkaline rocks such as nepheline syenites and carbonatite complexes.

The Cs content in intrusive rocks, as established by L. C. Arens in granites of Yugoslavia, varies widely. Cs is very mobile in metasomatic processes, during which it most frequently accumulates. He believes that the Cs content of rocks may be taken as

an extremely sensitive indicator of a rock's origin.

In criticism, we may mention that L. C. Arens frequently compares analyzed samples without considering their geologico-petrographical environment; this makes the interpretation of the data very difficult.

The report by E. Ingerson (USA) discusses the conduct of trace elements in the formation of granites and related pegmatites. The reporter noted a lower content of rare earth elements in the Ce group in the monazite of pegmatites than in the monazite of granites, which is also rich in lanthanum.

He emphasized that the rare earth content in monazites from the same deposits were found to be the same by entirely different laboratories: in the USA (K. I. Murat) and in the USSR (E. E. Bainstein).

A study of the rare earth content of monazites of various pegmatites in Minas Gerais (Brazil) led the reporter to conclude that the content of rare earth elements in the yttrium group relative to that of the cerium group increases by the end of pegmatite crystallization. He explains this fact in the following way: it is known that yttrium phosphates are generally less soluble and precipitate more easily than do cerium phosphates. It may be assumed that during the pegmatite crystallization, rare earth elements remain in the form of soluble complex compounds and are more stable in the yttrium group than in the cerium group. Consequently, the yttrium group is harder to keep in phosphate form than is the cerium group and remains longer in solution.

A long report represented by V. S. Koptyev-Dvornikov, M. G. Rub, E. F. Negrya, and L. V. Dimitriyev discusses trace elements in the intrusive complexes of granitoid composition in relation to general petrological regularities in the formation of these complexes.

The dark-colored and accessory minerals of granitoids, with few exceptions, crystallize later than do the principal parts of feldspars and quartz, according to the reporters. This concept has been confirmed in recent years, particularly by the studies of L. V. Dimitriyev on microstructures of granites.

The reporters believe that the original magma of granitoid complexes was very close to biotite in composition and not related to basaltic magma. The origin of granitoid rocks is related to the assimilation of surrounding rocks in the depths. The magmatic differentiation is, according to V. S. Koptyev-Dvornikov, restricted to additional intrusives, dikes including pegmatites, and quartz veins (generally to postmagmatic ore deposits). A still further development of these ideas led V. S. Koptyev-Dvornikov to the conclusion that the magmatic differentiation does not involve the entire volume of the magmatic reservoir but is restricted to its marginal and apical parts.

On the basis of semi-quantitative spectral determinations of trace elements in igneous rocks, the authors draw the following conclusions:

1. Using the example of Central Kazakhstan, they demonstrate different groups of trace elements ("microparageny") related to intrusive complexes of differing ages. Older complexes contain elements of the iron group (Co, Ni), and Pb, Zn, and Cu. Younger intrusive complexes, on the other hand, are enriched with elements of the rare metal-polymetal association, such as Be, Mo, Sn, Zn, Pb. Thus the higher Be, Mo, and Sn content in rocks indicates the younger age of the complexes concerned.

2. Intrusives of the same age and petrographic composition, but occurring in different geological and structural zones are also somewhat different in their trace element content.

3. Additional intrusives and dikes inherit the association of accessory minerals and the microparageny of the principal intrusive facies.

4. The trace elements are distributed within the intrusives irregularly. The greatest variations have been established in the Be, Sn, Pb, Cu, and Zn content, while the Ba, Sr, Co, and Ni distributions are more or less uniform. The irregular distribution of trace elements is caused by both magmatic differentiation and hybridization and is consequently most sharply pronounced at the margins of the intrusives and in dikes. The Ga, Zn, Cu, Ni, Cr, and V enrichment of some rocks of the marginal facies, additional intrusives, and dikes is related to hybridization.

5. The conduct of trace elements during the crystallization of granites varies. Be, Rb, Li, and Sr are inclined to concentrate in the remaining molten magma. The same is true in the case of Sn (in tin-bearing granites), Hf, Th, and rare earth elements. The content of Ba, P, and Zn, on the other hand, drops, in the remaining magma, during crystallization.

The irregular distribution of trace elements in granitic complexes is, according to the reporters, related to the original irregularity in the composition of the granitic magma; this in turn is related to differing environments. The differences can perhaps be best understood by following the concept of the palingenic origin

of the granitic magma.

The report presented by V. S. Koptyev-Dvornikov and others became the subject of serious criticism, especially on the part of some geochemists. Sharp discussions arose on the irregular distribution of trace elements in granitic complexes. The concept was advocated by some petrographers, who suggested various explanations of this phenomenon. However, the concept was challenged by other reporters, who presented the actual data on the distribution of various elements, and by many participants in the discussion, who presented figures indicating the absence of sharp variations in the content of trace elements in granites. The differences in opinion may perhaps be explained by the following reasons:

1. The conclusions of the reporters on the irregular distribution of trace elements are based on semi-quantitative spectral analyses. However, semi-quantitative analyses can never substitute for the exact quantitative analyses, which use larger samples and frequently produce results that differ from those of spectral analyses.

2. In the case of many elements (especially chalcophile elements), superimposed (hydrothermal) processes, even if they can hardly be clearly distinguished, may alter the distribution of trace elements in rocks entirely.

The principal conclusion on the possibility of palingenic origin of granitic magma was also doubted by some persons during the discussion. As was pointed out by A. P. Vinogradov, a member of the Academy of Sciences, and by a number of other participants in the symposium, the further development of the theory will inevitably meet with serious difficulties, which remained unexplained in the report.

The report by A. P. Vinogradov, a member of the Academy of Sciences, presented a new concept on the origin and composition of the lithosphere based upon a study of isotopic ratios of a number of elements. The peculiarities of the isotopic composition of inert gases in intrusive rocks and in the air led the reporter to conclude that the earth's atmosphere was formed as a result of degasation of the earth. Numerous data on the isotopic composition of lead in igneous rocks and ores indicated, according to A. P. Vinogradov, a close relation of ore deposits to intrusives and the absence of any independent ore sphere in the earth. The data also indicated ore deposition in the earth's crust only during certain periods in geological history. The reporter draws the interesting conclusion that basic and ultrabasic rocks are much older than granites, the lead isotopes of which reveal more disturbed relations than in basalts and ultrabasic rocks. For example, the dispersions of isotopes of light elements increases from ultrabasic to acidic rocks.

The general tendency of isotopic relations in igneous rocks and meteorites toward disturbances can easily be recognized in the distribution of a number of chemical elements in these rocks--first of all, rare and scattered elements. In view of this fact, A. P. Vinogradov presented a theory according to which the basaltic and granitic spheres in the earth were formed as a result of melting and extraction of ultrabasic compounds (and partially of the earth's degasation).

The study of the distribution of trace elements in ultrabasic rocks is therefore most important, because, as one may expect, the distribution of these elements in the original crust of the earth must, according to this theory, be close to that in ultrabasic rocks.

N. V. Byelov presented a thesis on the crystallochemistry of the petrologic process.

During the floor discussion of Vinogradov's report, E. Ingerson introduced new data indicating the relation of known polymetallic deposits in the Mississippi-Missouri basin to intrusive rocks (although these deposits have long been considered to be of sedimentary origin by many geologists). Many deep holes drilled in recent years have recovered granites under these deposits; and now geologists in the USA do not doubt the magmatic origin of these deposits. The relation of the deposits to intrusives is also confirmed by the distribution of lead isotopes. However, the study of isotopic relations is generally not a simple problem. First of all, a comparison of the data of various laboratories is extremely difficult. It is possible only with the use of standard isotopic mixtures.

The question of the methods of analytical determination and standards arose especially during the discussion of the reports by V. S. Koptyev-Dvornikov, A. P. Vinogradov, L. C. Arens, and others and was debated in the symposium briefly. However, during the general discussion it became the subject of many speeches, particularly those of E. Ingerson, E. E. Bainstein, A. V. Rabinovich, L. C. Arens, and others. The majority of the speakers pointed out the urgent necessity of working out an exact and quick method of determining small amounts of trace elements.

L. C. Arens pointed out that the differences in the data from various laboratories, which frequently makes comparison of the results impossible, are not caused by inaccuracy of the analytical methods used but by the absence of uniform standards.

In his concluding speech, A.P. Vinogradov pointed out the absence of the necessary contact between "pure" geochemists and petrographers in the study of natural subjects and the differences in their approach to investigations. Many geochemists are inclined to consider the conduct of elements beyond the geological environment; on the other hand, some petrographers conservatively reject the most modern analytical methods and formulate their conclusions upon inadequate data. He expressed hope that geochemists and petrographers will work in closer collaboration and that petrographers will use exact analytical data furnished by geochemists. In connection with this, it is especially important to work out a quick and precise method for quantitative determination and to use universal standards.

On the basis of reports discussed in the symposium and the debates on them, the following conclusions may be drawn.

1. The symposium summarized the information concerning the distribution of rare and scattered elements in igneous rocks throughout the world. It became clear that geochemistry has entered a qualitatively new stage in recent years. Even in the recent past, geochemistry considered the determination of the average percentages of chemical elements in the earth's crust (clarkes) or in its particular geophases and in various kinds of rocks as its principal concern, but now these activities have been carried out. Naturally, in a number of cases the clarkes will be altered in the course of further detailed studies, and in some cases the changes will perhaps be substantial, but the principal problem of the future is not this.

In the present stage, the clarification of the conduct of chemical elements in petrogeny is unusually important and to this end the study of the distribution of rare elements in various petrographic provinces, phases, and facies of magmatic complexes in common rock-forming and accessory minerals of igneous rocks must be carried out. New problems require new methods. For example, in recent years a new method emerged and took form which now permits us to make balances of the distribution of rare elements in particular minerals or rocks, and new terms have been introduced, such as "mineral-carrier" and "mineral-concentrator," etc. Further development will bring us closer to the establishment of the relationship between the trace element content in intrusives and their occurrence in the form of deposits.

2. The symposium made it clear that the solution of genetic questions is to a lesser extent related to the average percentages of trace elements in rocks (clarkes) than to their anomalous deviations occurring locally in certain intrusives and regions, for these deviations reflect specific peculiarities in the formation of the intrusive masses concerned. That is, the study of such deviations opens the way for the use of many trace elements and their ratios as indicators of origin.

3. The symposium disclosed that despite the accumulation of a great many figures on the distribution of trace elements in igneous rocks, they are still inadequate for systematization. Besides, the present data largely characterizes the intrusive rocks, principally the granites. The distribution of trace elements in basic and especially ultrabasic intrusives and effusives is still hardly known. However, even at the present stage, certain conclusions can be drawn concerning the general regularities in the conduct of trace elements in the course of an intrusive development.

The available data indicates a regular change in the composition of trace elements along with the qualitative changes in the composition of common elements of rocks in the course of differentiation of a single magmatic source and the formation of various intrusive facies. Trace elements are thereby more sensitive to changing environments and their content varies within much greater limits during the crystallization of magma. Consequently, it is clear that certain rare and scattered elements are excellent indicators, reflecting the conditions under which an intrusion takes place and of the course of intrusive development.

4. The symposium established that not all the trace elements are suitable indicators of the changing course of an intrusive development. The data reveal that the most sharply pronounced quantitative changes occur in the case of those elements in which the geochemical characteristics, such as ionic radii, potential of ionization, etc., are close to those of the common rock-building elements. For example, the properties of Rb, Tl, and to a lesser extent, Cs, are close to those of K, Nb and Ta to Ti, rare earths of the Y and Ce groups to Ca, and so on. These analogues of the common rock-building elements are very sensitive to peculiarities of an intrusive development; any chemical change in the environment will immediately affect their ratios, depending on amphoteric properties of the elements involved, the solubility or stability of their minerals in the presence of gas-fluxing compounds, or in oxidizing and reducing conditions. Consequently, the ratios of coupled trace elements become the most sensitive indicators of the magmatic processes. Among these ratios we may mention Rb:Cs, Rb:Tl, Nb:Ta, Σ Cs: ΣY, etc.

5. The trace elements with sharply pro-

nounced chalcophile properties cannot always be used as indicators of petrogeny. When interpretating the analytical data, one must keep in mind the possible hydrothermal origin of these elements, which is a very common case. However, even in these cases, the disclosure of their anomalous content may help to determine general characteristics of the specific metallogeny of the intrusives concerned.

6. Despite many important factors which may complicate the results of a normal geochemical evolution of intrusives, such as the assimilation of surrounding rocks, pneumatolytic-hydrothermal alterations, tectonic environment, and the loss of gas-fluxing compounds because of tectonics, etc., intrusive complexes of differing ages and different regions show identical trends of changes in the content of rare and scattered elements. The available data permits us to speak of two opposite tendencies in the conduct of trace elements. The content of some of them, such as of Zn, Ti, and V, etc., gradually decreases in the course of intrusive development, while others, such as Rb, Tl, Cs, and Ta, and rare earth elements of the Y group, become accumulated in the remaining magma.

These tendencies are likely to be controlled by a number of factors, among which the ionic radius is the most important. Elements with greater ionic radii show a tendency to become accumulated in the remaining magma. In the case of some elements, other factors appear to be more important. Particularly in the case of Nb-Ta, the closer relationship of Nb to Ti than of Ta to Ti appears to have special significance. Differences in the solubility stability of one or another complex compound is apparently very important in the case of many ions of high valence.

7. The distribution or concentration of some trace elements is greatly affected by the alkaline content of a magma. An increased alkaline content leads to the concentration of a number of trace elements in the remaining magma. In alkaline rocks, the concentration of such elements as Nb, Ta, Tr, Zr, and Hf and the formation of their own minerals is usually not related to the magmatic intrusion as such, but to postmagmatic, particularly autometasomatic processes. This is apparently related to the fact that the above elements form easily soluble complexes in alkaline environments and consequently remain in solution for a long time.

The distribution of trace elements in alkaline rocks is still little known and could not be a subject for discussion in the symposium. However, the available data from certain regions permits us to define their geochemical trend in alkaline intrusives. For example, Nb, Th rare-earth elements of the Ce group concentrate in early intrusive facies, such as nepheline syenites or alkaline syenites, while Ta, U, and rare-earth elements of the Y group are rather related to autometasomatic processes taking place when the latest facies (alkaline granites) of the intrusive complex solidify.

8. In analyzing the conduct of trace elements, one must keep in mind, besides the general tendencies discussed above, the conditions under which the particular intrusive complexes were formed. The most important of these conditions are:

(a) The content of rare and scattered elements in the original magmatic source on which, first of all, the specific metallogeny of the region depends.

(b) The assimilation of surrounding rocks and the enrichment of the magma with certain elements. This factor, as convincingly demonstrated by V. S. Koptyev-Dvornikov, is one of principal importance in the margins of intrusive bodies.

(c) The depth of the intrusive's solidification, which first of all controls the maintenance or loss of gas-fluxing compounds and consequently the distribution of trace elements in the rocks of direct magmatic crystallization, or their concentration in pegmatites and pneumatolytic-hydrothermal formations.

(d) The tectonic environment of intrusion, which largely depends on the geological-structural position of the magmatic source, in turn affects the extraction of trace elements in the form of gas-fluxing compounds.

Being unable to discuss all the details concerning each of these factors, we merely point out that in many cases they become the leading controls.

9. The analogy of the geochemical tendencies during the evolution of granitic intrusives to those of pegmatites is remarkable. In both cases one group of elements is inclined to become concentrated in the final products of crystallization, while the other group precipitates during its early stages. The identical conduct of trace elements during the solidification of granites and pegmatites indicates common regularities which control these processes; this is one of the best arguments in favor of the magmatic origin of pegmatites.

The final session of the symposium summarized the systematically gathered material on the distribution of trace elements in intrusive complexes of granitic composition. Many aspects of this complex problem are still not clear. However, certain paths along which we have to proceed are now in sight.

This type of symposium should be undertaken systematically in order to work on the following subjects:

(a) The conduct of trace elements during the evolution of basic and ultrabasic intrusives.

(b) The conduct of trace elements during the formation of various types of alkaline complexes (ultrabasic-alkaline to acidic-alkaline).

(c) The conduct of trace elements in the case of assimilation of different rocks by a granitic magma.

(d) The conduct of trace elements during autometasomatic processes in acidic and alkaline rocks.

(e) The ways in which trace elements can be used as indicators in the study of the relations of postmagmatic ore deposits to intrusives.

Reference Section

A Partial List of Reviews and Summaries of Russian Geologic Literature
prepared by
George V. Chilingar

Durov's classification of natural waters and chemical composition of atmospheric precipitation in USSR: a review: Am. Geophys. Union, Trans., 37 (2):193-96. 1956.

Use of hydrochemistry and temperature of underground waters in petroleum exploration: a review: Am. Geophys. Union, Trans., 36 (4):673-74. 1955.

$SO_4^=$ and Cl^- content of atmospheric precipitation in USSR: a summary: Am. Geophys. Union, Trans., 37 (4). 1956.

Selected list of Russian references of sedimentology: Am. Geophys. Union, Trans., 37 (2):245-51. 1956. (co-author, R. D. Terry).

Soviet methods of reporting and displaying results of chemical analyses of natural waters and methods of recognizing oil-field waters: a summary: Am. Geophys. Union, Trans., 38 (2):219-21. 1957.

Summary of "Concerning some additional aids in studying sedimentary formations," by M. S. Shvetsov: Jour. Sed. Petrology, 25 (3): 229-34. 1955. (co-author R. D. Terry).

Soviet classification of carbonate rocks and chemically precipitated $CaCO_3$: a review: Am. Assoc. Petroleum Geologists, Bull., 39 (9): 1885-89. 1955.

Review of Soviet literature on petroleum source-rocks: Am. Assoc. Petroleum Geologists, Bull., 39 (5):764-68. 1955.

Siderite geochemical facies of seas and saline waters in general as oil-producing, by G. I. Teodorovich: Am. Assoc. Petroleum Geologists, Bull., 39 (5):762-64. 1955.

Chemical composition of hydrocarbons of dispersed organic matter in sedimentary rocks, by Yu. N. Petrova and I. P. Karpova: Am. Assoc. Petroleum Geologists, Bull., 39 (7): 1417-19. 1955.

Physical-chemical characteristics of basins and sediments of Taman Peninsula: Am. Assoc. Petroleum Geologists, Bull., 39 (8): 1668-69. 1955.

[1] Reprints of these reviews are still available from the writer.

Distribution of petroleum and natural gas in oil deposits of Apsheron Peninsula in relation to lithology of enclosing rocks, by Sh. F. Mekhtiev and G. P. Tamrazyan: Am. Assoc. Petroleum Geologists, Bull., 39 (10):2094-96. 1955.

Is $O^{18}:O^{16}$ ratio in carbonate rocks an accurate geologic thermometer? Brief review of Russian literature: Am. Assoc. Petroleum Geologists, Bull., 39 (11):2349-50. 1955.

Temperatures of formation and transformation of petroleum, by S. I. Mironov, G. D. Galpern, and Yu. A. Kolbanovskiy: Am. Assoc. Petroleum Geologists, Bull., 40 (4): 764-66. 1956.

Dedolomitization: a review: Am. Assoc. Petroleum Geologists, Bull., 40 (4):762-64. 1956.

Contribution of A. V. Frost to theory of origin of petroleum: a review: Am. Assoc. Petroleum Geologists, Bull., 40 (5):1035. 1956.

Origin of glauberite deposits in Karabugaz Gulf: a review: Am. Assoc. Petroleum Geologists, Bull., 40 (5):1032-34. 1956.

Soviet classification of sedimentary particles and Vasilevskiy graph: Am. Assoc. Petroleum Geologists, Bull., 40 (7):1714-15. 1956.

Migration of petroleum and secondary recovery as viewed by M. A. Kapelyushnikov: Am. Assoc. Petroleum Geologists, Bull., 40 (7):1725-26. 1956.

Black Sea and its sediments: a summary: Am. Assoc. Petroleum Geologists, Bull., 40 (11):2765-69. 1956.

Joint occurrence of glauconite and chlorite in sedimentary rocks: a review: Am. Assoc. Petroleum Geologists, Bull., 40 (2):394-98. 1956.

Abundance of carbonate rocks in European USSR: Am. Assoc. Petroleum Geologists, Bull., 40 (8):2022-23. 1956.

Geochemistry of thorium and uranium in clays and carbonate rocks of Russian platform, by V. I. Baranov, A. B. Ronov, and K. G. Kunashova: Am. Assoc. Petroleum Geologists Bull., 41 (1):146-48. 1957

About dynamics of septal development in tetracorals during ontogeny, by K. G. Voynovskiy-Kriger: Jour. Paleontology, 30 (2):406-11. 1956.

Summary of "About minerals - geochemical indicators and their significance in prospecting for ores of rare metals in pegmatites," by A. I. Ginzburg: Econ. Geology, pp. 748-50. 1955.

Summary of "About some mineral neogenesis in sedimentary rocks," by D. P. Serdiuchenko and L. V. Dobrotvorskaia: Compass, 32 (4): 367-71. 1955.

The mineralogy of the montmorillonite group: Compass, 31 (4):288-95. 1954. (co-author C. A. Richards).

Review of mineralogy and classification of micas: Compass, 33 (1):76-8. 1955.

Selected list of Soviet references of marine geology and oceanography: Compass, 32 (3): 220-27. 1955. (co-author R. D. Terry).

Sediments of Sevan Lake, Armenian SSR: Compass, 33 (3):275. 1955.

Selected list of Soviet references on clays: Compass, 33 (3):277-78. 1956. (co-author R. D. Terry).

Do monothermites constitute an independent group of clay minerals? Compass, 33 (4): 345-47. 1956.

Khanin's classification of reservoir rocks: Compass, 34 (4):335-39. 1957.

Shcherbov's nomogram for determining minimum weights of assays: Compass, 34 (4):340-41. 1957.

Geothermal gradients in USSR: Compass, 34 (2):160-62. 1957.

Addendum to "Geothermal gradients in USSR:" summary: Compass, 35 (2):137-38. 1958.

Reviews and summaries of articles on geochemistry in Russian literature: Compass, 34 (2):163-67. 1957.

Russian bibliography: Compass, 35 (2): 133. 1958.

Russian bibliography: Compass, 35 (3): 213. 1958.

Summaries of Russian articles in geochemistry: Compass, 35 (2):133-37. 1958.

Is the low degree of cementation of chalk caused by the secondary processes?: Compass, 35 (2):98-9. 1958.

Sponge spicule deposits as indicators of physical-chemical environment of deposition and diagenesis: Compass, 35 (3):215-19. 1958.

Lower Permian lithologic formations of the World, by A. B. Ronov and V. E. Khain: Compass, 35 (3):213-14. 1958.

A short note on types of porosity in carbonate rocks: Compass, 35 (1):69-74. 1957.

A short note on authigenic minerals: Compass, 35 (4):294-97. 1958.

Rapid method of determining mineralogic type of clays: Soil Sci., 83 (5):417. 1957.

Water study as exploration aid: Petroleum Engineer, pp. B119-21. April 1955.

Simplified techniques of determining calcium and magnesium content of carbonate rocks: Petroleum Engineer, 26 (12): 368-70. 1954. (co-author R. D. Terry).

Variation in the chemical composition of carbonate rocks of Russian platform, by A. P. Vinogradov, A. B. Ronov, and V. M. Ratynskii: Geochim. et Cosmochim. Acta. 12:273-76. 1957.

Some data on diagenesis obtained from Soviet literature: a summary: Geochim. et. Cosmochim. Acta. 13:213-17. 1958.

Chemical composition of oil-field waters from Apsheron Peninsula, Azerbaidzhan SSR: Geochim. et. Cosmochin. Acta. 14:168-72. 1958.

Facts and figures about oil and gas in USSR: SC Engineer, Univ. of Southern Calif. Pub., 9 (1):20, 33. 1958.

Some corrections in mechanical analysis by pipette method, by S. I. Malinin: Am. Jour. Sci. pp. 238-39. 1956.

Solubility of calcite, dolomite, and magnesite and mixtures of these carbonates: Am. Assoc. Petroleum Geologists, Bull., 40 (11):2770-73. 1956.